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Optimal Energy Scheduling of EVs Considering Battery Lifespan Deterioration with V2G Implementation: A Case Study of Khumaltar Feeder

by

Bibek Dahal

A THESIS

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled “Optimal Energy Scheduling of EVs Considering Battery Lifespan Deterioration with V2G Implementation: A Case Study of Khumaltar Feeder" submitted by Mr. Bibek Dahal (PUL-075-MSESP-003) in partial fulfillment of the requirements for the degree of Master of Science in Engineering in Energy System Planning and Management.

____

Supervisor, Dr. Laxman Poudel
Professor
Department of Mechanical and Aerospace Engineering
Pulchowk Campus, IOE

____

External Examiner, Dr. Daniel Tuladhar
Associate Professor, HOD
Department of Mechanical Engineering
Kathmandu University

____

HOD, Dr. Sudip Bhattrai
Assistant Professor
Department of Mechanical and Aerospace Engineering
Pulchowk Campus, IOE

Date: 8th October, 2023

ABSTRACT

Environmental issues like climate change, pollution, and others are becoming more and more of a worry, which is prompting people to look at alternatives to the current fossil fuel-based transportation system. The benefits of electric vehicles (EVs), such as minimal emissions, reliability, silent operation, efficiency, etc., are making them more and more popular. Electric vehicles are regarded as a reliable and clean source of energy. However, switching completely to electric vehicles will have a significant negative impact on the existing distribution system. When everyone gets home from work and begins electric vehicle charging at once at their rated capacity (uncoordinated charging), which is also the peak hour for residential load, increase in load due to EV charging may lead to network stability problems. This research project aims to optimally discharge battery energy back to the grid so that EV users can profit more. But as the battery is continuously charged and discharged, its lifecycle shortens, making battery replacement more burdensome for EV customers. In this study, the depth of discharge at each hour of the day is taken into account in an effort to reduce the expense associated with battery deterioration. The work is carried out in IEEE modified 15 bus system and then in a real feeder of Nepal. The Firefly Algorithm, one of the metaheuristic algorithms, is used to determine the optimum charging and discharging rate.

The whole work is divided into three different scenarios. In scenario 1, EVs start fast charging as soon as they return home. They discharge at their rated value during day time period when electricity tariff is high. This scenario acts as a reference case for the next two scenarios. In scenario 2, EVs are charged in a controlled way so that voltage of the system doesn't go beyond the limit. Scenario 3 is similar to that of scenario 2 except that the renewables like wind turbine and solar PV are integrated into the system. For the study period, the voltage profile, system loss, and EV charging and discharging power are all plotted. When EVs are charged and discharged while there are renewable energy sources present in the system, the system is found to operate at its best. For scenario 3 and scenario 2, the voltage profile is optimal. In addition, compared to the first two scenarios, losses are minimal in scenario 3. In contrast to scenario 2, the battery lifecycle for scenario 3 is better.

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LIST OF ACCRONYM AND ABBREVIATION

EV	Electric Vehicle
IEEE	Institute of Electrical and Electronics Engineers
USD	United States Dollar
SOC	State of Charge
SOH	State of Health
SOA	Safe Operating Area
V2G	Vehicle to Grid
G2V	Grid to Vehicle
TOD	Time of Day
DOD	Depth of Discharge
FA	Firefly Algorithm
PSO	Particle Swarm Optimization
ABC	Artificial Bee Colony
SEI	Solid Electrolyte Interface
HSA	Harmony Search Algorithm
PU	Per Unit
DG	Distributed Generation
WT	Wind Turbine
PV	Photo Voltaic
DSM	Demand Side Management

CHAPTER ONE: INTRODUCTION

1.1 Background

The recent decade has seen an alarming increase in greenhouse gas emissions which plays a crucial role in getting utility companies to focus on creating a clean, dependable, and sustainable energy system. This environmental concern of climate change has also affected Nepal directly which can be observed as the heavy melting of snow in mountains. This has led to the need of use of clean energy sources such as wind, solar, hydro for power generation and use of EVs for locomotion. The pollution level in Kathmandu valley has already reached into alarming state with major contribution of petroleum driven vehicle. The solution to this issue is the use of electric vehicle for transportation. Therefore, a significant contribution of large-scale electric vehicle (EV) integration is thought to be a practical approach to reduce carbon emissions and improve the environment.

The growing urbanization and increasing use of transportation vehicle has resulted in use of fossil fuel every year. The consequence is environmental pollution such as degradation of air quality, greenhouse gas effect and climate change. Nepal has begun the use of E-mobility since long time ago. The use of ropeway between Kathmandu and Hetauda, Trolley buses in Kathmandu are few examples of E-mobility which were in use almost half a decade back in Nepal. Though the use of E-mobility in Nepal had initiated long time back but due to lack of proper policies and attractive incentives in the EV, its use has not been able to grow. Though the study has shown Nepal having immense potential of 83000MW of hydro energy, but country lack on harnessing it to its potential. Due to this Nepal has been dependent on other sources like petrol, diesel, LPG etc. imported from its neighboring nations. This shows that of we can realize our hydro potential sufficiently, use of imported fossil fuels can be highly reduced contributing on nation’s economic status and also resulting in clean environment.

Many technological challenges arise from the expected rapid market adoption of EVs. Uncontrolled EV charging and discharging could jeopardize the power system's reliability and security. For the purpose of charging and discharging EVs, intelligent scheduling must be used. One of the main sources of fuel, solar radiation, is present in plenty worldwide, including Nepal. Though the tiny portion of total radiated energy from sun reaches earth yet it is enough to meet the world's need. The human civilization has been harnessing solar energy in the form of heat and light since the beginning. Only fraction of total solar energy from reaching earth has been harnessed for human uses such as solar water heating, solar cooking, solar lighting, space heating and cooling of buildings, solar engines for water pumping, high temperature process heat for industrial purposes and electricity generation. Solar heat engines or solar thermal technology and solar photovoltaic technology are two ways of solar power electricity generation.

Nepal has the perfect condition to harness the solar energy as it lies at latitude of 30^o in northern hemisphere and experience 300 days of sunshine in a year. Study has shown Nepal having potential of 2100 MW of solar power generation [1]. The use of solar in the distribution feeder helps to reduce the losses and also improve the voltage profile of the distribution network increasing the resiliency of the system. EVs have the benefit over traditional cars in that they can run on locally produced power. Battery of EV can be used to store the energy produced using solar energy during day time and this power be used in during the peak hour (V2X).

A system known as vehicle-to-grid, or V2G for short, enables energy to be returned from an electric vehicle's (EV) battery to the electrical grid. Bi-directional charging is made feasible by V2G technology, which pushes energy from the battery in the vehicle back to the power grid while simultaneously charging the EV battery. Although the terms "bi-directional charging" and "V2G" are frequently used interchangeably, there is a little distinction between the two. While V2G technology only permits the flow of energy from the vehicle's battery back to the grid, bi-directional charging refers to two way charging (charging and discharging).

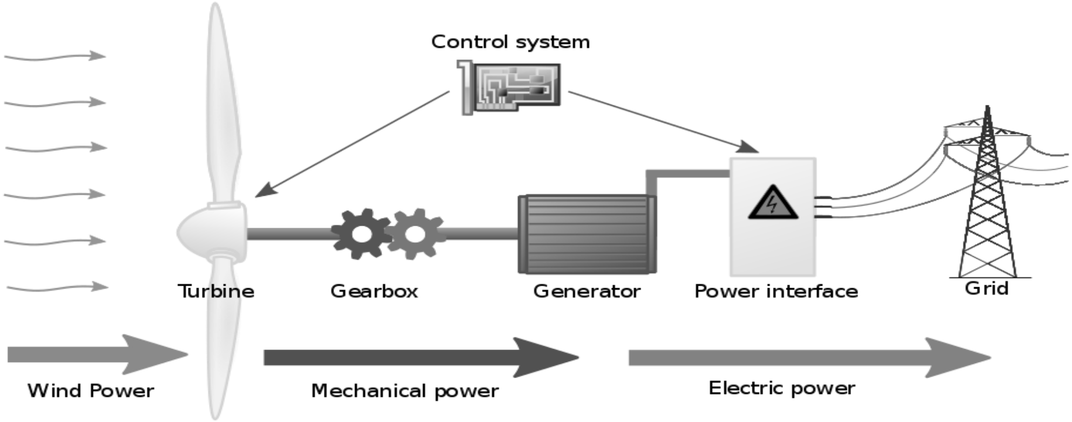


Figure 1.1: Wind Power Plant Model

Wind is the result of the unequal heating of the atmosphere by the sun, the uneven surfaces of the earth (mountains and valleys), and the planet's rotation around the sun. Wind is one of the renewable energies available in nature. Electricity from wind power is generated by converting wind energy into rotating energy of the blades and converting that rotating energy into electrical energy by the generator.

1.1.1 Battery Lifespan:

While battery lifespan refers to how long a battery lasts before needing to be replaced, battery life refers to how long a device can operate before needing to be recharged. Since it is difficult to determine the ageing of each battery cells, the prediction of lifespan of battery becomes a complicated task. But prediction is necessary for the improvement of reliability and thus usability of the electric vehicle battery. The ageing is caused due to the growth of a surface film known as the solid electrolyte interface (SEI) on the surface of the electrode. Thus the conductivity of the electrolyte is affected and the internal resistance of the cell increases. The result is a decrease in the battery capacity. The battery life is the time where the capacity of the battery lies above a minimum accepted capacity. This battery life of the battery is dependent upon the depth of discharge (DOD) of the battery, number of charge discharge cycles and the age.

The state of health (SOH) of any battery is an important factor to check the wellness of the battery. It describes the energy content after considering the ageing effects of the battery. Efficiency of the battery is an important factor to remove the range anxiety from the EV drivers. Thus battery state of charge (SOC) should be considered along with SOH to give the actual energy content (fuel) to the EV users. Due to ageing of the battery, the battery capacity decreases and hence its range decreases. In determining the fuel content of the EV, if the ageing factor is not considered the EV will give the shorter range than expected.

1.1.2 Battery Management System:

The design of a battery-powered device requires many battery-management features, including charge control, battery-capacity monitoring, remaining run-time information, charge-cycle counting, etc. Each component of the system must be nearly perfect for it to be able to provide great precision. Thus Battery Management System (BMS) is required which ensure that optimum use is made of the energy inside the battery powering the portable product and that the risk damage to the battery is prevented. This is accomplished by monitoring and controlling how the battery is charged and discharged. **[BMS 1]** BMS limits the ageing effects and increase the lifetime of the battery. Without proper monitoring of the battery cells in the battery pack, the cell may experience the hotspots which may lead to failure. The failure of the each battery cell may affect the performance of the whole battery pack. The complexity and thus cost of BMS depends upon the functions and intelligence used for the management of the system. One of the crucial roles of a battery management system is SOC estimate. Although the name "battery" refers to the entire pack, the monitoring and control capabilities are only applicable to specific cells or modules (groups of cells) inside the overall battery pack assembly. Each battery cells in the battery pack is affected by its temperature. Therefore it is very important to integrate the thermal management system in the BMS. BMS makes sure that the interconnected cells are balanced both electrically and thermally so that its lifetime can be extended. Thermal management system in the BMS can be of active and passive type. However, a passive system that uses only the ambient temperature can provide the required thermal control for the battery packs whereas active type can also be used.

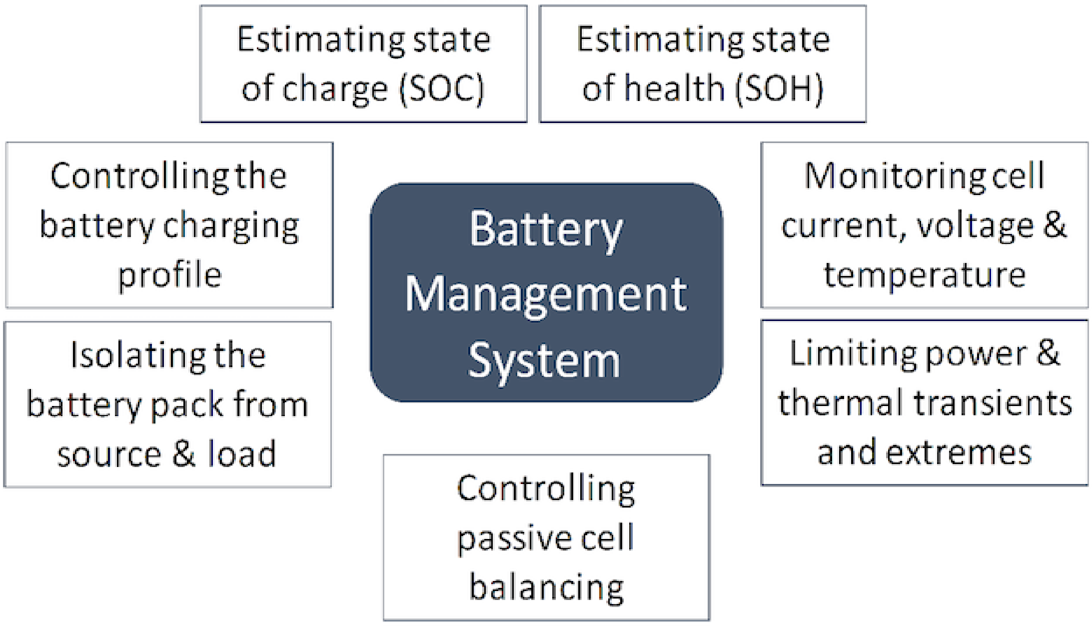


Figure 1.2: Functions of Battery Management System (BMS)

The battery management system (BMS) is an advanced hardware and software system that performs the following common functions:

- Voltage measurement and control
- Current
- Isolation monitoring
- Temperature measurement and control
- Sate of charge/health calculation

The BMS's ability to measure and regulate cell voltage may be its most crucial feature. The BMS typically keeps an eye on the voltage of each series group of cells. Voltage excursions due to overcharge, over discharge, or high power pulses can lead to significantly reduced life and safety issues. The next function of BMS is to control the charging and discharging current of the battery as too high current may lead the overheating of the system causing system failure or malfunctioning. The cells may experience the overvoltage and under voltage issues that hampers the battery life if charging and discharging is done without proper coordination.

Temperature control of the battery pack and cells is another function of the BMS. Temperature is another factor that has a big impact on lifespans and safety. Different methods are utilized for regulating and keeping an eye on cell temperatures depending on the application. To enable the control process to modify heating, cooling, or pack power levels as needed, the BMS must have enough data regarding temperature variance throughout the battery pack.

The status of charge/state of health (SOC/SOH) duty for a battery management system may be the most complicated one. While SOC is a simpler indicator of the percentage of electrons available to conduct work relative to a completely charged battery, SOH provides a more thorough analysis of the battery's overall performance capability when compared to its initial performance when new.

An accurate SOC calculation is required due to a number of considerations, including the indicated vehicle range, the engine's operating mode and calibration, and electrical power limits, including charging rate. A correct SOC value is necessary since these dependencies are significant as vehicle attributes. It is currently not feasible to measure SOC directly. Therefore, state of charge is used to determine SOC using cell voltage measurements, current integration, transient response of cell voltage, and cell temperature. [6] An additional function of the BMS is communication with additional vehicle controllers. The BMs are able to forecast the battery pack's potential in the near future and frequently suggest changes to the vehicle's operation in response to observed battery pack conditions. Transmitting information to the driver, such as the vehicle's operating mode, range, and any new issues, also requires communication.

Most of today's all-electric vehicles and PHEVs (Plug-In Hybrid Electric Vehicles) use Li ion (lithium-ion) batteries. Li ion batteries have numerous advantages such as improved energy density, discharge tolerance, cycle life, re-charge times with a low memory effect etc. Regardless of having mentioned advantages Li-ion batteries still have a number of shortcomings, particularly with regards to safety. Li-ion batteries have a tendency to overheat, and can be damaged when supplied with overvoltage and overcurrent. Hotspots inside the battery cells can boost the unnecessary chemical reactions inside the battery. Thus BMS plays its role to avoid overvoltage and overcurrent situation that may arise during charging and discharging of electric vehicle.

1.1.3 Techniques to improve Battery Life

From above points, we see that by balancing the cells, managing individual cell overvoltage and overcurrent, and managing the cells' internal temperatures, the BMS can extend the battery's lifespan. The next important factor that can extend the life of the battery is by reducing the maximum depth of the discharge of the battery and the number of charge discharge cycles of the battery. Serious damage to the cells results from charging the battery to its maximum SOC and then discharging it at a high depth of discharge. The lifespan of the battery can be increased, according to the literature, if the SOC is kept between 20% and 80%.From the above points, we see that BMS can improve the lifetime of the battery by balancing the cells, control of overvoltage and overcurrent of individual cell and thermal management of the cells. The next important factor that can extend the life of the battery is by reducing the maximum depth of the discharge of the battery and the number of charge discharge cycles of the battery. Charging the battery to its maximum SOC and discharge at high depth of discharge affects the cells seriously. Literatures show that if the SOC of the battery is maintained between 20% and 80% then the lifetime of the battery can be extended.

1.2 Problem Statement

a. A large number of EVs being charged uncontrollably (G2V) makes the distribution grid unstable. If EVs are randomly charged, the distribution system may experience issues including power shortages, voltage sags, significant power loss, etc.
b. V2G that only prioritizes managing energy rather than maximizing profit for EV users demotivates users, which prevents them from participating in V2G.
c. The continual charge discharge method used in V2G and G2V energy exchange reduces the lifespan of batteries and burdens EV consumers.

1.3 Objective

Main objective of the study is energy scheduling of an EV considering its battery condition with V2G implementation.

Specific Objectives of study are:

- To observe system performance while charging EVs both randomly and in coordinated way and see how the system is affected by the addition of renewable energy sources.
- To study chances of enhancing the efficiency of power distribution by including battery deterioration model in V2G energy transfer.
- To simulate IEEE 15 Bus System and apply it to the Khumaltar Feeder, a real-world system in Nepal.

1.4 Scope and Limitation:

- The research can be utilized to forecast the system's voltage and power losses for both the test bus and the actual system.
- The impact of renewable energy sources can be examined in the system, and further economic analysis can be done to see whether it is practical in the actual world.
- Research doesn’t consider feasibility of the considered renewable energy sources, solar and wind in this study, in considered Khumaltar Feeder.
- Location of solar plant and wind turbine in the system is a research limitation. Research work does not provide optimal position for these system, which are instead put in some practically workable area rather than optimal location. Additionally, size of the solar panel and wind turbine are chosen at random.
- Type and number of electric vehicles connected to the system are chosen at random. Therefore, research work is not specific to any one form of EV and may produce varied results for other vehicle types.
- Since there isn’t any TOD tariff system for domestic consumers in Nepal, tariff used for the model development is completely random.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Environmental issues including pollution, climate change, and global warming are becoming more and more of a concern. As a result of attributes like minimal emissions, silent operation, efficiency, etc., electric vehicles are becoming more and more popular. Integration of electric vehicles on a large scale has been seen as a successful strategy for the environment's urgent need to reduce carbon emissions. [2]. Electric vehicles have advantages over conventional gasoline-powered vehicles, including the potential to reduce CO2 emissions and operate on locally available electrical power to exchange energy between vehicles and the grid (V2G) during peak hours. The benefits of electric vehicles are not limited to the transportation industry; they may also reduce power fluctuations from renewable sources and increase income through their usage as batteries. [3] [4]. Precise EV charging coordination is required to achieve an effective interface to the control framework. Without consistent coordination between EVs, the distribution system encounters issues including large losses brought on by overloading from uncontrolled charging of EVs. Furthermore, widespread use of electric vehicles could result in a decline in voltage profile, an increase in technical losses, and high peak demand. [5].

EVs contribute significantly to demand side management by enabling flexible charging schedules based on the time of day. With the use of smart charging techniques, load shifting and peak shaving are possible. Additionally, electric vehicles have the capacity to provide power to the grid during periods of high peak demand, which lowers the price of electricity and produces income for electricity users. As part of a V2G system, EVs' batteries provide electricity to the grid, offering an affordable alternative to an unreliable battery farm. [6]. However, as they account for the majority of the market for vehicle to grid energy, electric vehicle consumers are very concerned about the replacement cost of EV battery due to its deterioration. Additionally, it is unclear to the EV manufacturers whether to offer a warranty for the batteries that participate in the V2G energy exchange market. In order to reduce the operational expense of the distribution network, a challenge relating to the coordination of the charge to the battery storages for electric vehicles has been modelled in [5]. The findings showed that charging of electric vehicles enhances the voltage profile of the system and lowers technical losses when distributed generation (DG) is incorporated into the distribution network.

The issue of classifying various charging behaviors, calculating the peak demand due to EV charging, and figuring out the amount of power available for electric car battery discharge is examined in [7]. In the two-stage optimization model, the first stage lowers the system peak load with the most number of available electric vehicles, while the second stage reduces the system peak load with the most number of available electric vehicles while minimizing system fluctuation during the peak load. By charging the vehicles at a constant charging power, the suggested method ignores the cost associated with deterioration and calculates the annual profit obtained by peak shaving. In [8], By incorporating a solar system, chillers, and gas turbine into the system, three different charging types—uncoordinated charge, fast charging, and smart charging—as well as the energy exchange from the vehicle to the grid were evaluated. The smart charging technology distributes the load over time by shifting electric vehicle charging from peak to valley hours in order to improve system stability. When a large number of EVs were integrated into the system, the vehicle to grid power transfer technology reduced the power input from the gas turbine.

For controlled charging of plug-in electric vehicles, a technique for optimization has been described in [9] that includes a control unit in centralized form. For the analysis in this study, a constant battery lifecycle is assumed. However, the DOD of the battery affects how long a battery lasts. According to the model in [10], energy transfer to the grid is profitable due to the battery's lower capital cost and the provision of ancillary services like peak clipping during peak hours and reserve capacity during a typical circumstances. For the optimal power distribution of the micro-grid, Lu has designed a multi-objective function that includes wind generators, solar panels, diesel generators, and micro turbines [11]. The suggested approach reduced the operating costs of the EVs by charging them during the day's lower tariff time, which produced peak shaving. The study findings demonstrated how DG and controlled EV charging were strongly integrated to lower system costs and load variance. The study finds that even while V2G reduces load variance and boosts system stability, lower battery quality and higher deterioration costs prevent customers of electric vehicles from benefiting from it.

In [12], the charge coordination problem has been solved by using V2G scheme in an unbalanced distribution network. The study's proposed approach minimizes power losses and satisfies voltage constraints while accounting for load uncertainty to provide the best possible electric vehicle charging. The findings indicate that the V2G technique in distribution networks is not financially advantageous since the advantages associated with its use are outweighed by the shorter EV battery life and higher battery replacement expenses. The goal of this study is to reduce system running costs by examining the charging and discharging schedule for electric vehicles. However, this literature does not model the cost of battery degeneration for charge/discharge states.

2.2 EV Charging

As electric vehicles (EVs) gain popularity, various methods of EV charging have emerged to cater to different needs and charging infrastructure availability. The on-board charger and off-board charger terms refer to the locations of the chargers that are used to transfer power from the grid to the batteries of electric vehicles. Off-board chargers are positioned outside the vehicles, while on-board chargers are positioned inside. The on-board charger's power output is constrained by its size and weight, but the off-board charger is more flexible in terms of output power. In order to guarantee that the battery is optimally charged, both the on-board and off-board chargers must include the control and communication circuit in real-time with the BMS of the EV. This is done to prevent the battery from being harmed by overload or other unnatural circumstances. In most cases, onboard chargers are used for AC charging. While DC charging and battery switching, off-board chargers are employed. On the other hand, inductive charging utilizes both on- and off-board chargers simultaneously. In consideration to some of the common methods of EV charging are listed below:

A. Level 1 Charging (110V or 120V)
B. Level 2 Charging (220V or 240V)
C. DC Fast Charging (Direct Current Fast Charging or Level 3 Charging)
D. Wireless Charging (Inductive Charging)
E. Battery Swapping

2.2.1 Level 1 Charging (110V or 120V):

This is the simplest and slowest way to charge an EV. It consists of using a regular charging cord to connect the EV to an ordinary household socket. Level 1 charging is often utilized overnight or when there are no other charging choices. It offers slow charging, often adding 2 to 5 miles of range per hour.

2.2.2 Level 2 Charging (220V or 240V):

Level 2 charging is a quicker and more popular charging technique for home, commercial, and public charging stations. The installation of an exclusive 240V charging station, also known as an EVSE (Electric Vehicle Supply Equipment), is necessary. Depending on the car and the charging station's capacity, level 2 charging can add 10 to 30 miles of range per hour.

2.2.3 DC Fast Charging (Direct Current Fast Charging or Level 3 Charging):

The quickest charging technique for EVs is DC fast charging. Bypassing the onboard charger, it supplies high-voltage DC power directly to the vehicle's battery. For speedy top-ups, DC fast chargers are frequently located next to roads, on main thoroughfares, and in populated regions. Depending on the car and charger, DC fast charging can extend the range by up to 100 miles in just 20 to 30 minutes.

2.2.4 Wireless Charging (Inductive Charging):

By using electromagnetic fields to transfer energy between a charging pad on the ground and an EV's receiver, wireless charging does away with the necessity for physical charging connections. The energy transfer starts immediately when the EV is parked over the charging plate. Although it is more convenient than conventional alternatives, wireless charging often functions at a lesser charging rate.

2.2.5 Battery Swapping:

Battery swapping includes replacing a drained EV battery at a swapping station with a fully charged one. As the battery swap only takes a few minutes, this method can offer a speedier "refueling" experience than conventional charging. This technology is less popular than others since it needs standardized battery packs and specialized infrastructure.

2.3 Smart Charging

Three broad categories of charging technologies relevant to school bus electrification are:

- Unmanaged charging, in which EV connect to a charger and the maximum amount of energy possible is transmitted from the electrical system to the vehicle. There is no consideration for how charging may affect the electrical grid; it happens whenever it suits.
- Managed charging (or “V1G”), in which the time and power level of charging are controlled to maximize benefits to the customer and the electric grid.

- Bidirectional charging (or “Vehicle to Everything/V2X”), a two-way energy flow in which batteries are charged and later discharged using a bidirectional charger.

Managed charging is the proactive, controlled charging of electric vehicles in a manner that is beneficial to the customer and electric grid either by shifting the time or power level of charging. Managed charging can be broken into two types:

Passive – relies on influencing customer charging behavior via incentives, guided communications, or varying electricity costs based on time of charging. Most often, these price signals are done through Time-of-Use (TOU) rates that are highest when energy is the most expensive to generate.

Active – relies on signals from the electric utility or aggregator to a vehicle or charging station to manage charging activity. An example of this is demand response (DR) in which the utility will communicate to program-enrolled customers through varying means (phone call, email, text, etc.) to reduce charging to relieve electricity generation shortfalls or to increase charging to take up excess energy often from renewable generation.

Managed charging can produce benefits for customers and the electric grid. Depending on how it is implemented, managing charging can support various goals, including:

- Cost Savings for Customers – With managed charging, electric vehicle charging can take place outside of peak demand periods, when energy is being used by the most customers, which often results in lower rates and/or an electricity bill credit

- Remote Scheduled Operation – Managed charging can be done remotely or at planned intervals, allowing operators and drivers to be absent during the actual charging session, which often lasts several hours. This is especially important with electric school buses because the most opportune time for charging is often overnight when staff is unavailable.

- Renewable Energy Integration – Electric vehicles can charge when there is peak renewable energy production for sources like solar and wind. This can increase the overall output of renewable energy by reducing instances of curtailment, in which renewable energy production is intentionally decreased below maximum output to match demand.

- Energy Use Reduction – Electric vehicle charging can be delayed or shifted to avoid electricity outages when available energy supply does not match anticipated demand. Reducing energy use (load) can also help reduce greenhouse gas emissions through avoidance of having to start up less efficient and more polluting generators, called peakers, to meet these shortfalls. Moreover, these peaker units are often located in disadvantaged communities.

Smart charging is the process of recharging EVs in a way that preserves a flexible, affordable, and sustainable charging environment. To build a managed and effective charging environment, it entails a number of smart functions. Following are the some of the benefits of smart charging.

- Smart charging allows for the control of charging power, charging time, and charging duration. Additionally, it facilitates the bidirectional flow of power.

- Because EVs may be charged during off-peak hours, the usage rate of the power system's infrastructure, such as power transformers and transmission lines, is high. This lowers the cost of charging as well.

- The distribution network is more stable and the efficiency of power transfer is increased when EVs are charged during off-peak hours and discharged back to the grid during peak hours.

- By serving as the storage for such renewable energy sources and discharging during peak hours, EVs can assist in removing the intermittency issue if renewable energy sources like solar and wind are added into the system. The EV users will benefit from this as they earn money.

V2X

Vehicle-to-everything, or V2X, is a broad energy technology concept in which an electric vehicle is seen as a mobile battery that may discharge stored energy for some benefit. Electric vehicles' batteries can provide power for a building or home. V2B and V2H are used to refer to them, respectively. V2X is a general word used to handle all of these concepts. V2X can be applied in different ways depending on the end use. Four applications are described in the chart below.

- **Vehicle-to-Building/Home (V2B/H):** Stored energy is transmitted to a building or home, usually to fulfill the need of backup power or avoid peak energy use demand charges.
- **Vehicle-to-Grid (V2G):** Stored energy is discharged beyond the site meter out to the greater electric grid with the purpose of mitigating peak energy demand and/or for compensation of the site owner.
- **Vehicle-to-Load (V2L):** Stored energy is released to supply energy for another load, like running machinery for building or other separate energy-hungry appliances.
- **Vehicle-Grid-Integration (VGI):** The vehicles are charged and discharged in accordance with grid demand in order for them to function as a grid asset.

V2X technologies offer a variety of benefits to vehicle owners and grid operators. These include:

- **Grid Flexibility** – By supplying energy back into the grid or momentarily meeting the end-use power needs of a building, residence, or other load, V2X services give grid operators an on-demand power source that they can use during times of high energy demand.

- **Opportunities for Compensation** – Vehicle owners, such as school districts and other operators, can be financially compensated for the V2X services they provide to the electric grid. This may come in the form of an electricity bill credit to offset other electricity consumed at the site.
- **Emergency Preparedness** – In times of emergency, there may be electric utility power outages or power disconnects, but V2X services can supply back-up power for shelters, homes, command centers, and other locations.
- **Support of Renewables** – V2X enables more efficient use of energy from renewable resources by storing excess renewable energy when it is abundant and releasing that energy when it is not.

V2X energy transfer is categorized as smart charging and offers the following advantages:

Renewables like solar and wind are intermittent in nature. Thus in order for the system to work efficiently and reliably, large energy storage systems are required which are expensive. EVs can act as such storage system to store energy and discharge during peak hours and other necessary hours.

- By discharging the energy during the peak hours when the electricity tariff is high, both the system operators and EV users can get benefit.
- Electric vehicles can be used as the emergency power supplies. For example, during the Japan earthquake the affected area got isolated from the grid. Nissan leaf electric vehicles batteries were used for the emergency power back up.
- Apart from selling the energy during the peak hours, the EVs can also provide other ancillary services and earn extra revenue.

Though V2X has many benefits, there are also some challenges:

- The network should support the bidirectional flow of power which are very expensive compared to unidirectional system.
- When the discharging of the power back to grid is done, the charging and discharging cycles of the EV increases. This will reduce the lifetime of the battery due to deterioration of the battery.

- The complexity and cost associated with the V2X energy transfer makes the standardization of the system difficult.
- The implementation of the vehicle to grid is not possible for all vehicles currently.

Though the manufacturers have started to produce vehicles that support bidirectional flow of power, there are huge numbers of EVs in the market that support only unidirectional power flow. Also in order to carry out the V2G energy transfer, higher level of communication is required in between the charger and the EV which are not available in the type 1 and type 2 AC chargers. However, bidirectional off-board EV chargers support the V2G energy transfer and lots of pilot projects are going throughout the world.

Whether to charge or discharge the battery is determined by following points:

1. Local load balancing
2. Proper utilization of renewables
3. Charging based on electricity price
4. Peak shaving and valley filling
5. Emergency and ancillary services

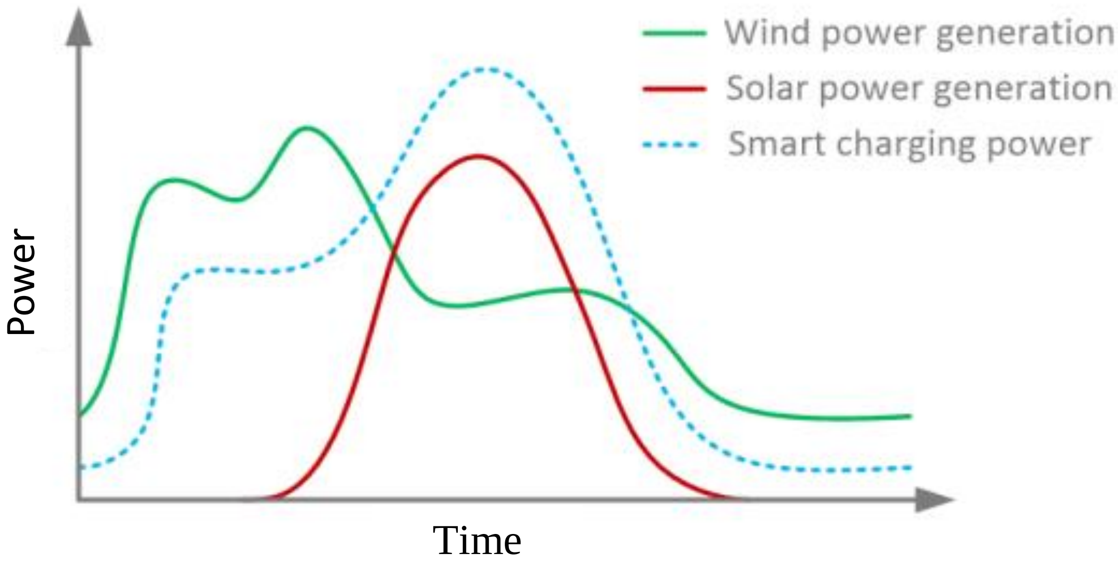


Figure 2.1 Renewable Energy Utilization

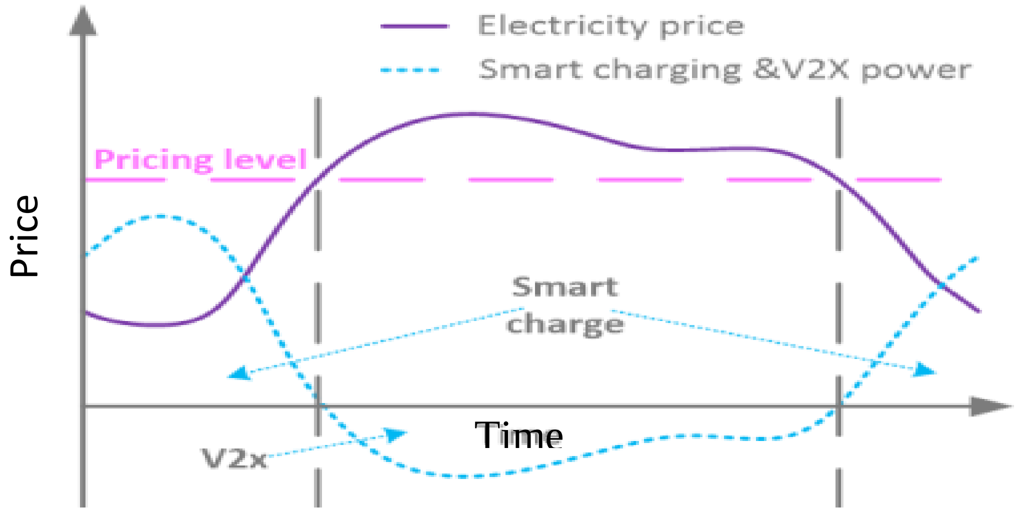


Figure 2.2: Price Based Charging

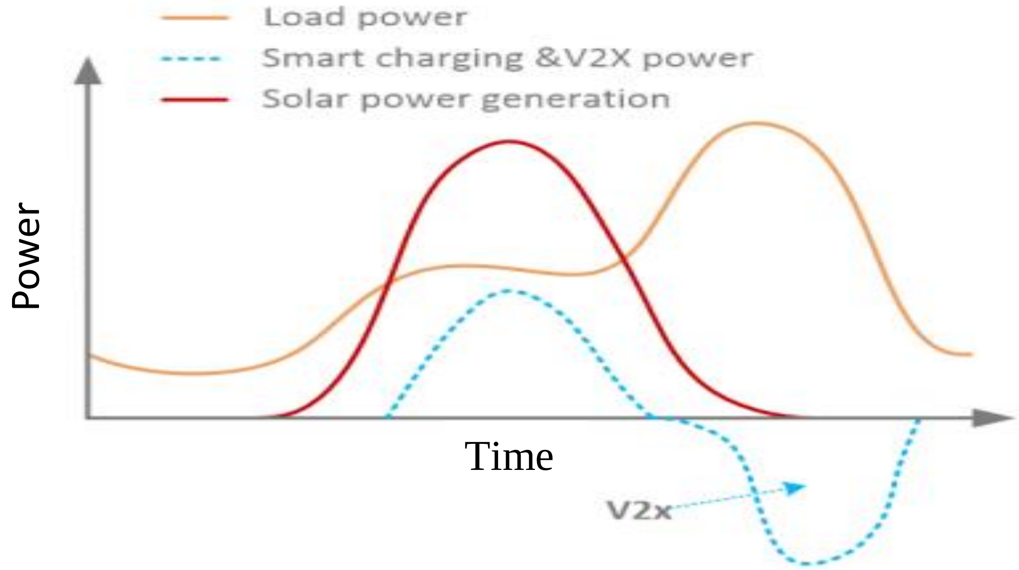


Figure 2.3: Peak shaving by use of EV

The above figures represents graphical representation of expected results after the implementation of smart charging of Electric vehicle in a system. Figure 3 represents the intermittent nature of renewables and their use accordingly by implementation of smart charging. Figure 4 represents tariff price vs time of smart charging which implies that by the use of smart charging the EV batteries gets charged during off peak hours i.e. when tariff is low and discharges power back to the grid during peak hours that is when tariff is high. Figure 5 representation how peak shaving can be performed by the help of smart charging thus improving load curve.

CHAPTER THREE: METHODOLOGY

The methodology followed for doing the study can be understood from the flowchart as shown below:

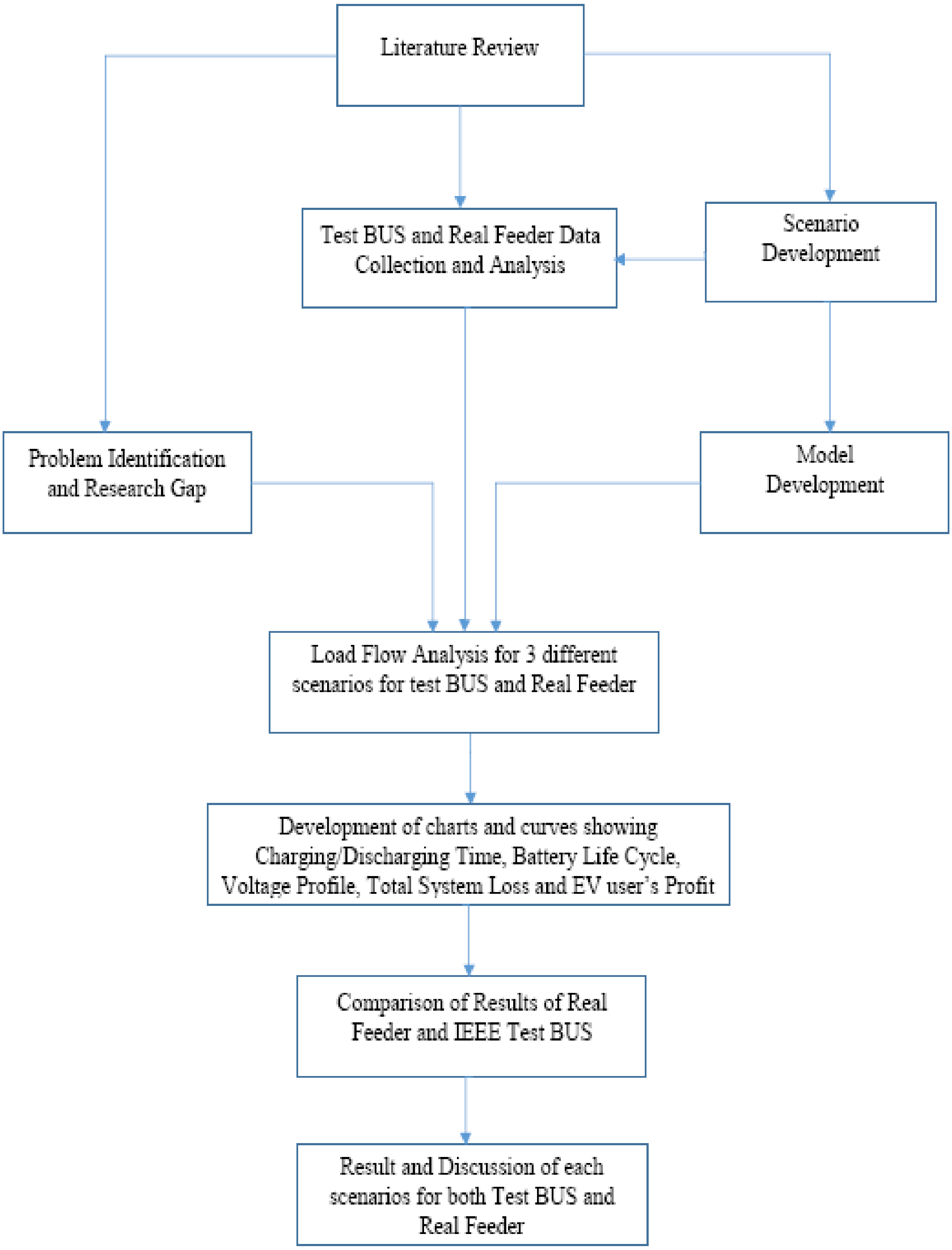


Figure 3.1: Methodological Flowchart of Research

3.1 Modelling of renewables and battery degradation cost

3.1.1 Wind turbine model

Wind is the result of the unequal heating of the atmosphere by the sun, the uneven surfaces of the earth (mountains and valleys), and the planet's rotation around the sun. Wind is one of the renewable energies available in nature. Electricity from wind power is generated by converting wind energy into rotating energy of the blades and converting that rotating energy into electrical energy by the generator.

Worldwide, there are wide variations in wind patterns and speeds that are influenced by geography, vegetation, bodies of water, and even the rotation of the globe. It is necessary to convert wind energy into mechanical or electrical power in order to use it. Wind turbines are utilized to accomplish this, turning the kinetic energy of the wind into mechanical power. This mechanical power can then be employed for tasks like pumping water from wells and grinding grain. It can also be transformed into electrical energy by utilizing a generator and used locally or connected to the grid. One of the most economically viable renewable electricity generation technologies in recent years is wind energy. Wind energy can already successfully compete with conventional electricity generation at good windy locations.

Contrary to using electricity to generate wind like a fan would, wind turbines use the wind itself to generate power. Although they can seem simple, wind turbines actually have a lot of mechanical components. With the help of their blades, turbines are made to transform wind energy into mechanical power. Typically, a turbine's shaft is mounted with two to three blades. A wind turbine, in the simplest terms, transforms the kinetic energy of the wind into electrical energy. If the wind speed is exceedingly low or nonexistent, the wind turbine's ability to generate any useful electricity will also be nonexistent. The majority of commercial turbines are built to produce power at a minimal speed of the turbine known as the "cut-in" speed. Typically, this speed is in the range of 4 meters per second. On the other hand if speed of the wind turbine exceeds certain limit then the generation ceases. The 'cut-out' speed is the speed at which wind turbines stop producing power as a means of protection. Typically, this occurs when the wind speed is around 25 meters per second. In order to produce power, wind turbines must operate between the cut-in and cut-out speeds. Additionally, it's remarkable to observe that the turbines reaches their peak energy output right in the midst of this cut out and cut in speeds. This usually occurs when the wind speed is between 12 and 14 meters per second. When the wind speed doubles, the power output multiplies by eight since the power generated by the wind is proportional to the cube of the wind speed. However, if the wind speed is cut in half, the power production is just 1/8th of what it was. Therefore, it's crucial to locate wind turbines in locations with high average wind speeds and little to no turbulence. The turbines are erected in tall towers because the wind speed is high above the ground, resulting in faster and less turbulent winds. The output power from the wind turbine is dependent upon the velocity of the wind and is given by the following relation

$$P_h^w = \begin{cases} 0 & v_h \leq v_{c,i} or v_h \geq v_{c,o} \\ P_{\max}^w * \frac{vh - v_{c,i}}{v_{rt} - v_{c,i}} & v_{c,i} \leq v_h \leq v_{rt} \\ P_{\max}^w & v_{rt} \leq v_h \leq v_{c,o} \end{cases}$$

where P_h^w represents the power output from the wind turbine, P_{max}^w represents the maximum output power from the turbine, v_h represents the velocity of the wind at different hour h, v_{rt} is rated speed of wind turbine, $v_{c,i}$ and $v_{c,o}$are the cut in speed and cut out speed respectively.

3.1.2 Solar PV Model

Electromagnetic radiation, which are the sun's heat and light waves, travels from the sun to the surface of the planet. Solar Photovoltaics, sometimes known as Solar PV, is frequently utilized as the foundation technology for renewable energy. A phenomenon known as the photovoltaic effect occurs when certain substances, or semiconductors, are exposed to light and produce an electric current. This effect occurs due to the absorption of photons (light particles) by the semiconductor material, which results in the generation of electron-hole pairs. These separated charges create an electric voltage across the material, leading to the production of an electric current. For this process to occur, the energy of the incident photons must be greater than or equal to the material's work function, which is the minimum energy required to liberate an electron from the material's surface. As a result, the photovoltaic effect provides a direct conversion of light energy into electrical energy, making it a fundamental principle behind photovoltaic cells, commonly referred to as solar cells. As mentioned earlier when photons strike, or are absorbed by the right sort materials, they effectively ‘knock’ electrons out of their natural spot in an atom. This produces an electron with a negative charge and a hole with a positive charge. Now that they are more stable together than apart, this electron-hole pair is being looked for recombination. However, if we combine the correct materials, we may induce this electron to move through a circuit before it recombines with the hole. As a result, we produce electricity, which is nothing more than the flow of electrons. The fundamental components of a solar PV module or panel, modern solar PV cells are constructed from layers of semiconductors like silicon. The primary innate and environmental variables that affect solar PV cell performance. Capacity Factor, Conversion Efficiency, Sunlight Intensity, Shadow, and Temperature are a few examples. The performance of solar PV systems is significantly influenced by temperature. Contrary to popular belief, solar PV cells actually lose efficiency as the temperature rises. Additionally, solar PV cells become more effective as the temperature drops. This results in a situation where there is a compromise between temperature and sunshine intensity. The solar photovoltaic array's power output is contingent upon the sun irradiation and ambient temperature at each time interval under consideration. The power from the solar PV is given by:

$$\mathrm{P}_{out}^{pv} = \mathrm{P}_{rt}^{pv} * \frac{\mathrm{I}}{\mathrm{I}_{ref}} * [1 + \tau\{(\mathrm{T}_{amb} + (0.0256*\mathrm{I})) - \mathrm{T}_{ref}\}]$$

where P_{out}^{pv} represents the power output from the solar PV, P_{rt}^{pv} represents the maximum power at standard condition, I represents the solar irradiation in watt per meter square, I_{ref} represents the solar radiation at standard temperature (I_{ref} = 1 kW/m2), T_{ref} represents standard temperature (25 °C), τ is a constant taken as 3.7×10^{-3} (1/ °C), and T_{amb} (°C) represents the ambient temperature of the solar PV.

3.1.3 Battery degradation cost model of EV

Figure 6 shows how the cost-benefit analysis connects the various discharge power and DOD values. The quantity of energy utilized by the battery is measured using DOD. The graph demonstrates that costs rise together with the battery's DOD and the amount of power it can discharge at a given DOD. The battery's capacity and SOH both decline as a result of the high DOD. The equation below illustrates the relationship between cost and depth of discharge of the battery and how battery degradation occurs when the battery is discharged at high depths of discharge. According to the equation provided, the battery lifespan is an exponential function of the battery's depth of discharge.

$$C_h^{b,d} = \frac{C_{b,cap} * P_h^{ev} * \Delta h}{E_{cap}^{ev} * l_c(dod_h^b) * \eta_b{}^2}$$

$$l_c(dod_h^b) = 694 * (dod_h^b)^{-0.795}$$

$$dod_h^b = 1 - \frac{E_h^{ev}}{E_{cap}^{ev}}$$

where $C_h^{b,d}$ represents the battery degradation cost of the battery at any hour h, $C_{b,cap}$ represents the capital cost of the battery, P_h^{ev} represents the power discharged by the battery at any hour h, Δh represents the time interval taken as one hour for this study, E_{cap}^{ev} represents the total battery capacity, l^c represents the number of cycles of the battery, dod_h^b denotes the depth of discharge (DOD) of the battery and E_h^{ev} represents the energy discharged by the battery at any hour h.

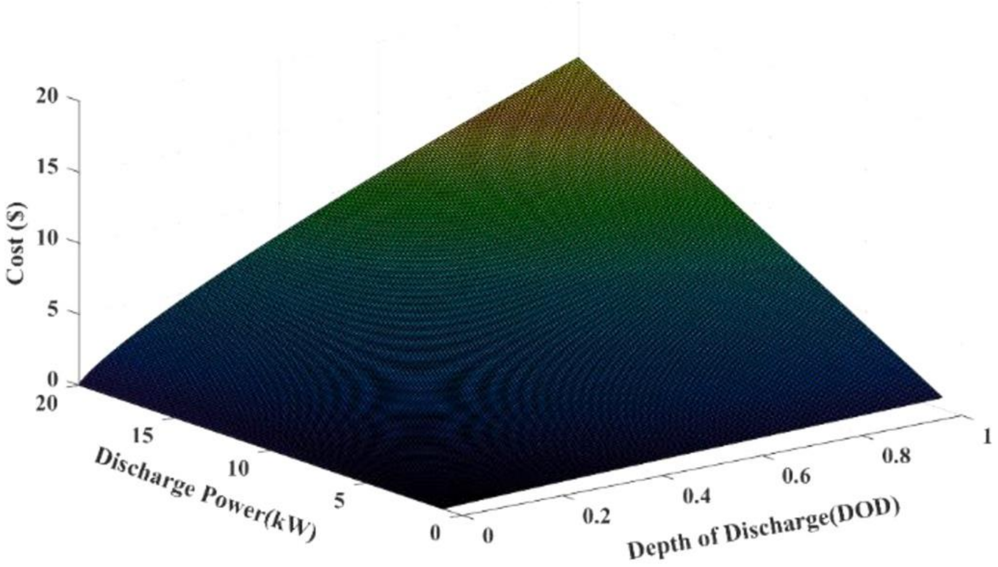


Figure 3.2: Battery cost relation with DOD and discharged power

3.2 Problem formulation

The electric vehicles have the flexibility of consuming the power from the grid and supplying power back to the grid. Such facility of the EVs helps to improve the resiliency of the distribution network. The method proposed in this study minimizes the overall cost of the distribution network also inspiring the EV users to participate in the V2G energy exchange program by also considering the cost due to degradation of the battery. Thus the objective function considered for this study the cumulative sum of the residential cost, commercial cost, EV charging cost, battery degradation cost and the cost associated with the power losses in the system. It is formulated as:

$$\text{Objective= Min } \sum_{h \in \emptyset t} (C_h^{res} + C_h^{com} + C_h^{ev} + C_h^{b,d} + C_h^{los})$$

$$C_h^{res} = \sum_{rt \in \emptyset b} P_{r,h}^{res} * \delta_{res}$$

$$C_h^{com} = \sum_{rt \in \emptyset b} P_{r,h}^{com} * \delta_{com}$$

$$C_h^{ev} = \sum_{rt \in \emptyset b} P_{r,h}^{ev} * \in_{ev}$$

$$C_h^{los} = \sum_{sr \in \emptyset l} I_{sr,h}^2 * \Re_{sr} * \boldsymbol{\lambda}$$

Where $C_h^{res}, C_h^{com}, C_h^{ev}, C_h^{b,d}$ *and* C_h^{los} indicates residential cost, commercial cost, EV charging cost, battery degradation cost and cost associated with the losses respectively. EV charging cost is negative during the discharging and positive during charging. Variables δ_{res}, δ_{com} and ε_{ev} represents the residential, commercial and electric vehicle electricity tariffs rate respectively. I_{sr} represents the bus current, $\Re_{sr}$ denotes the bus resistance responsible for the power loss of the network and λ represents the cost associated with the losses in the network.

3.2.1 Active power and reactive power constraints

$$\sum_{sr\in\varphi_l} \mathrm{P}_{sr,h} + \sum_{r\in\varphi_b} \mathrm{P}^{g}_{r,h} + \mathrm{P}^{ren}_{r,h} = \sum_{rt\in\varphi_l} \mathrm{P}_{rt,h} + \sum_{rt\in\varphi_l} \mathrm{I}^2_{rt,h} {*} \Re_{rt} + \sum_{rt\in\varphi_b} \mathrm{P}^{res}_{r,h} + \sum_{rt\in\varphi_b} \mathrm{P}^{com}_{r,h} + \sum_{rt\in\varphi_b} \mathrm{P}^{ev}_{r,h}$$

here $\mathrm{P}_{sr,h}$ indicates active power of branch sr, $\mathrm{P}_{r,h}^{ren}$ indicates power from the renewables (wind turbine and solar PV), $\mathrm{P}_{r,h}^{g}$ denotes the generated power at bus r, $\mathrm{P}_{r,h}^{res}$ and $\mathrm{P}_{r,h}^{com}$ indicates the active residential and commercial loads respectively.

$$\sum_{sr\in\varphi_l} \mathrm{Q}_{sr,h} + \sum_{r\in\varphi_b} \mathrm{Q}^{g}_{r,h} = \sum_{rt\in\varphi_l} \mathrm{Q}_{rt,h} + \sum_{rt\in\varphi_b} \mathrm{Q}^{res}_{rt,h} + \sum_{rt\in\varphi_b} \mathrm{Q}^{com}_{rt,h} + \sum_{rt\in\varphi_l} \mathrm{I}^2_{rt,h} {*} \mathrm{X}_{rt}$$

Here, $\mathrm{Q}_{sr,h}$ indicates reactive power of branch sr, $\mathrm{Q}_{r,h}^{g}$ indicates the generated power at bus r, $\mathrm{Q}_{r,h}^{gen}$ and $\mathrm{Q}_{r,h}^{com}$ denotes the reactive residential and commercial loads connect at bus r respectively.

$$|\mathrm{P}_{sr,h}| \leq V_{\max} {*} \mathrm{I}_{\max}$$

$$|\mathrm{Q}_{sr,h}| \leq V_{\max} {*} \mathrm{I}_{\max}$$

$$\mathrm{P}^2_{sr,h} + \mathrm{Q}^2_{sr,h} \leq V^2_{r,h} {*} \mathrm{I}^2_{sr,h}$$

Here, $V^2_{r,h}$ denotes bus r voltages, $V_{\max}$ and $\mathrm{I}_{\max}$ represents the maximum bus voltage and maximum branch current respectively

$$V_{\min} \leq V_{r,h} \leq V_{\max}$$

3.2.2 Electric Vehicle Power and its State

$$\chi^{ev}_{ch,h} + \chi^{ev}_{dch,h} + \chi^{ev}_{i,h} = \chi^{ev}_{h}$$

$$\chi^{ev}_{ch,h} {*} \mathrm{P}^{ev}_{ch,\min} \leq \mathrm{P}^{ev}_{ch,h} \leq \chi^{ev}_{ch,h} {*} \mathrm{P}^{ev}_{ch,\max}$$

$$\chi^{ev}_{dch,h} {*} \mathrm{P}^{ev}_{dch,\min} \leq \mathrm{P}^{ev}_{dch,h} \leq \chi^{ev}_{dch,h} {*} \mathrm{P}^{ev}_{dch,\max}$$

$$\mathrm{E}^{ev}_{h} = \mathrm{E}^{ev}_{h-1} + (\chi^{ev}_{ch,h} {*} \mathrm{P}^{ev}_{ch,h} - \chi^{ev}_{dch,h} {*} \mathrm{P}^{ev}_{dch,h}) - (1 - \chi^{ev}_{h}) {*} \mathrm{E}^{ev}_{trv,h}$$

$$\mathrm{E}^{ev}_{\min} \leq \mathrm{E}^{ev}_{h} \leq \mathrm{E}^{ev}_{\max}$$

Here, $X_{ch,h}^{ev}$, $X_{dch,h}^{ev}$ and $X_{i,h}^{ev}$ represent the binary statuses for the charging state, discharging state and idle state of EV respectively. X_{h}^{ev} denotes the electric vehicle status when connected to the distribution network. $P_{ch,h}^{ev}$ and $P_{dch,h}^{ev}$ denotes the electric vehicle charging and discharging power, E_{h}^{ev} denotes the present electric vehicle battery capacity at any specific time and $E_{trv,h}^{ev}$ is the energy that represents EV travelling. Fig 2 represents the flowchart of the charging schedule that has been proposed in this study. This research work implements forward backward propagation method for the distribution load flow analysis in the test bus and then in the real feeder. The bus voltages and power losses (total and each hour losses) are calculated for the distribution network. The firefly algorithm is used to determine the minimum operating cost of the network.

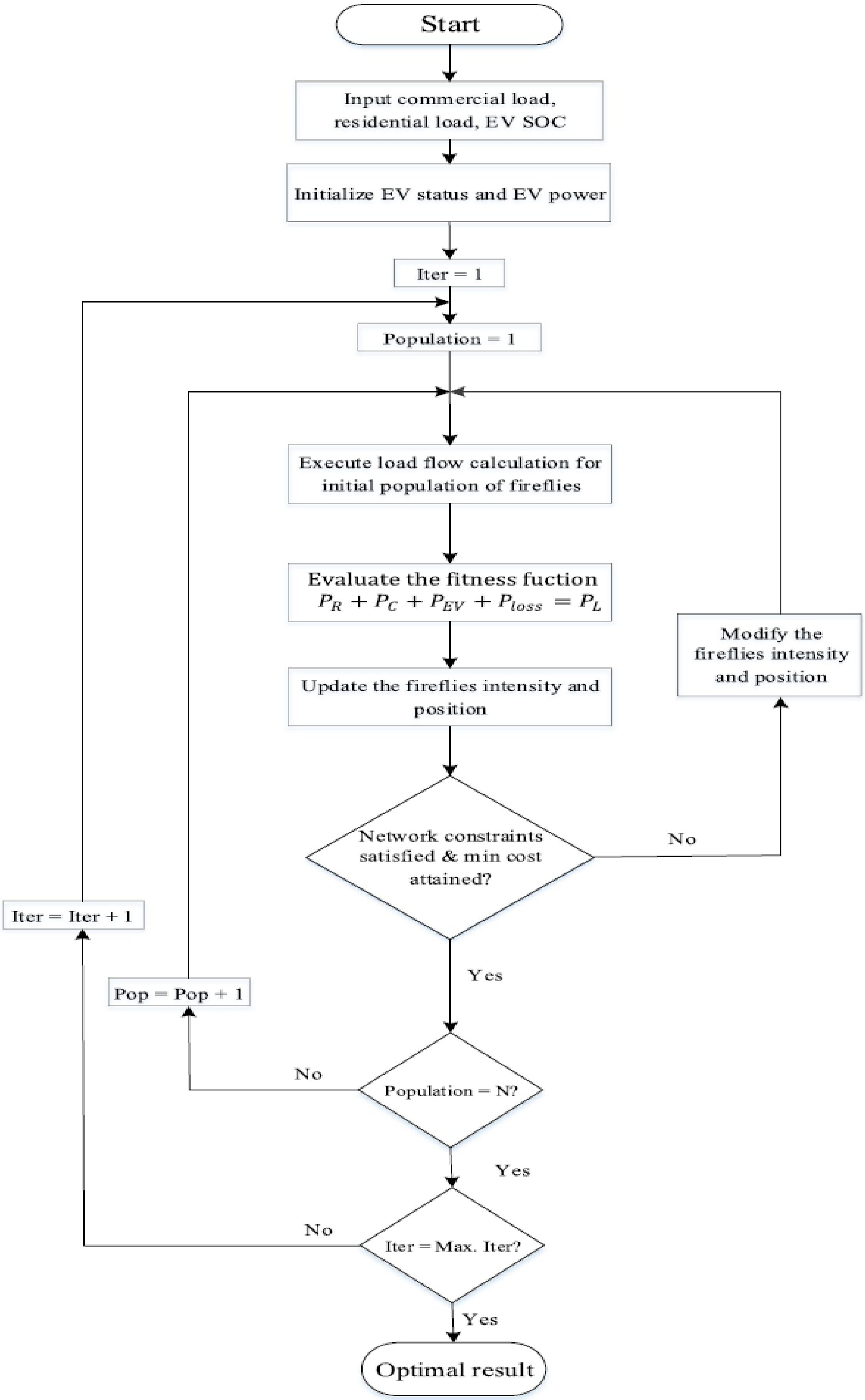


Figure 3.3: Flowchart of the Proposed charging method

3.3 Performance Evaluation parameter

3.3.1 EV user profit

Users of electric vehicles are concerned with the financial viability of V2G applications. The expense associated with battery deterioration is deducted from the revenue generated by users of electric vehicles in this study. Therefore, in order to maximize their savings, owners of electric vehicles choose to discharge their batteries during times of high tariff. The ratio of the total power discharged by the electric vehicle

$$\text{Profit}=\frac{(P_{V2G,h}{}^{*}\varepsilon_{ev})-C_{h}^{b,d}}{\sum_{h=1}^{24} P_{dch,h}^{ev}}$$

divided by the amount of power exchanged through energy discharged to the grid (PV2G, h) is used to calculate the profit equation.

3.4 Optimization algorithm

The firefly algorithm is one of the optimization algorithm that uses meta-heuristic technique to determine the optimum value of the objective function. It is based on the social nature of the fireflies. This algorithm was developed by Dr. Yang and is based on following three basic ideas:

1) The fireflies are unisex in nature and get attracted to the mating types.
2) The brighter flies attracts the lesser brighter flies.
3) But if the brighter flies are not found, they fly randomly in the given search space.

Firefly Algorithm is a population based optimization algorithm similar to other population search algorithms such as ABC, PSO and HSA. However, it is different from other optimization algorithms that it has the tendency of adjusting the parameters that depends very less on the algorithm and identify the search space in appropriate way.

The above listed ideas of FA can be elaborated in the following mathematical form:

3.4.1 Distance between flies

The separation in between two mating flies in the given search space is computed as vector operation done in Cartesian system between ith and jth firefly given by the equation:

$$r_{ij}=|Y_i-Y_j|=\sqrt{\sum_{D=1}^{s}(Y_{i,D}-Y_{j,D})^2}$$

Here r_{ij} represents distance in between two flies, s represents dimension of the control vector, $Y_{i,D}$ and $Y_{j,D}$ represents the Dth dimensions of Y_i and Y_j fireflies respectively.

3.4.2 Attraction between firefly

The attraction in between the flies' decreases when the two mating partner flies in opposite direction and the separation between them increases. The attraction in between fireflies can be denoted by the following equation:

$$\beta(r) = \beta_0 \times \exp(-\gamma r^m); \quad m \geq 1$$

Here, $\beta(r)$ and β_0 are the attractiveness when the flies are at the distance r and 0. γ represents the coefficient of light absorbed by firefly and m represents the number of fireflies taken as 2.

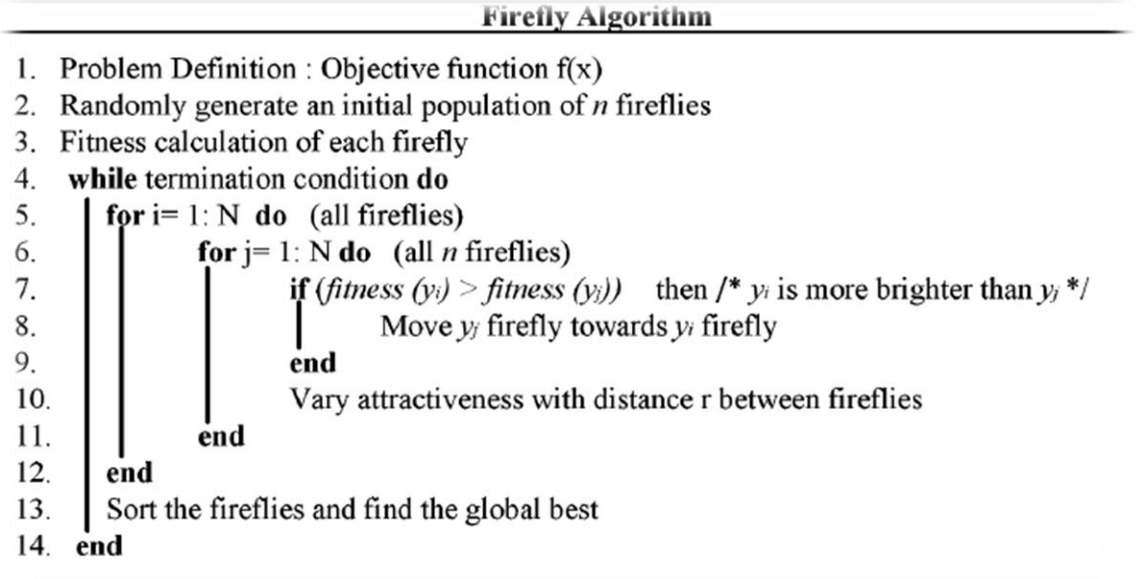
3.4.3 Movement of the fireflies

The less bright fireflies gets attracted towards the brighter fireflies. The movement between the two flies, jth firefly (having low intensity) towards the ith firefly (having high intensity) is represented by mathematical equation:

$$Y_j(t) = Y_j + \beta_0 \times \exp(-\gamma r^m) \times (Y_i - Y_j) + v_j$$

$$v_j = \delta(rand - 0.5)$$

The first term of the equation $Y_j(t)$ represents the current position of jth firefly. The second term is the intensity of brightness by which the jth firefly is attracted towards ith firefly. But, the last term v_j denotes the movement of j_{th} firefly in the whole search space when it cannot find flies with more brightness. The randomization parameter δ is a constant value that lies in the range between 0 – 0.5. Fig 15 shows the pseudo code of the FA [13].



Firefly Algorithm

```
Problem Definition : Objective function f(x)
Randomly generate an initial population of n fireflies
Fitness calculation of each firefly
while termination condition do
    for i= 1: N do   (all fireflies)
        for j= 1: N do   (all n fireflies)
            if (fitness ($y_i$) > fitness ($y_j$))   then /* $y_i$ is more brighter than $y_j$ */
                Move $y_j$ firefly towards $y_i$ firefly
            end
            Vary attractiveness with distance r between fireflies
        end
    end
    Sort the fireflies and find the global best
end
```

Figure 3.4: Pseudo code of Firefly algorithm

3.5 System to be considered

In this thesis, the G2V and V2G power transfer is carried out via a modified IEEE 15 bus network before being transferred to the actual Nepalese feeder, the Khumaltar feeder. Each bus in the distribution network is supposedly capable of charging or discharging eight EVs. The distribution networks include three solar PV and WT units. The electric vehicles used in this research has a maximum battery capacity of 85 KWh and 20 KWh of starting energy. The electric vehicle's specifications taken into consideration for this study are listed in table 1 above. Each bus's maximum voltage is set between 0.94 p.u. and 1.00 p.u.

The time frame for this research project is set at 24 hours a day, with study periods of one hour each, dividing the total time into 24 parts. Throughout the day, the wind's velocity affects the wind turbine's power output. The sun's radiation and the surrounding temperature affect how much solar power is produced. Figure 12 displays the day's temperature on an hourly basis. Figure 11 displays the power generated by each solar PV and wind turbine unit during a twenty-four-hour period. Figure 9 displays the cost of power for residential and commercial consumers at each hour of the day Figure 10 depicts the residential and commercial load curves for each hour of a day. At their respective peaks, the residential and commercial rates are greater.

All buses, except bus number 1, are equipped with three solar and wind energy generation units. Solar panels are rated at 100 KW, while wind turbines have a 275 KW rating each. The wind's ability to generate power is reliant on its daily fluctuations in wind speed. During the day, solar energy is at its highest and drops to zero at night and in the early morning. By taking into account three distinct situations, as detailed below, it is possible to observe the effects of both controlled and uncontrolled electric vehicle charging and discharge on the distribution network.

3.5.1 Scenario 1

In this scenario, the charging and discharging of the electric vehicle take place at random times. Once all the electric vehicles have arrived at their destinations and have begun to charge from the grid, an analysis of the voltage magnitude of the weakest bus, system losses, charging and discharging power of EVs, and system stability is performed. This scenario 1 serves as a baseline for the other two scenarios as well as when evaluating the algorithm's performance. Once the EVs are plugged into the network, this scenario charges them at their rated full charging rate. When the price of power is high during the day, they release the energy back into the grid, giving EV users additional benefits. No any optimization is used to determine the optimum value of the charging and discharging power.

3.5.2 Scenario 2

In this scenario the electric vehicles are charged and discharged in a controlled way. This method of charging does not allow the bus voltage to fall and rise above its set limit. This scenario's electricity cost usage is examined and contrasted with that of scenario 1. This scenario also examines technical losses, stability, and the weakest bus's system voltage when the EVs are charged under regulated conditions. The Firefly algorithm is used to determine the optimum value of the charging and discharging power. The algorithm computes this optimum power by minimizing the system cost which includes cost due to losses, residential cost, commercial cost and cost associated with charging and discharging of the EVs. The cost becomes negative during the discharging of the EVs meaning the users earn the profit during this period. The total system losses is expected to reduce, the voltage profile is expected to improve and stay within the limit in this scenario compared to scenario 1.

3.5.3 Scenario 3

This scenario has similarities to scenario 2, but it takes into account the effects of renewable energy sources (photovoltaic and wind turbine for the test bus, and only solar PV for the actual system). In addition to comparing the system stability to alternative scenarios, the cost of the system with controlled charging and discharging is examined. With the exception of the integration of renewable energy sources into the grid, this scenario is quite similar to scenario 2. The voltage profile of the weakest bus of the system, losses of the system and EV power will be analyzed in this case. The optimum value of the charging and discharging power will be computed from the Firefly Algorithm by minimizing the cost of the system. Three units of solar and three units of wind turbine will be connected to each bus of the system network except bus no 1 for test bus. But real feeder is integrated with only solar and no wind turbines in order to bring the practicability into the system. The power from the wind turbine depend upon the speed of the wind which varies throughout the day. The power from the solar PV depend upon the intensity of light radiation and temperature throughout the day. The power from the solar is highest during the day time so the EVs are expected to charge during this time. The total system losses is expected to be lower, the voltage profile of the weakest bus of the system is expected to improve and stay within the limit in this scenario compared to scenario 1 and 2.

Figure 9 shows the residential and commercial tariff for the period of twenty four hours. The residential and commercial tariff are not constant throughout the day. The commercial tariff is relatively higher than that of the residential tariff. At hour 8 and 9 the residential tariff is high since this is the period of peak hour in morning. The residential tariff again decreases from 10 and then increases from 15 until 21. Thus we can see that the residential tariff at morning and evening is higher compared to normal period. The tariff at period 15 16 is high though the residential load is low because during this period the commercial load is at its peak and to discourage the residential users the tariff is made high. Similarly the commercial load increases during day time so consequently electricity price is also high during this period. From 9 the tariff starts to increase until 22 and it is highest for the hours 12 15 16 and 17. Thus if the EV users can sell the energy during this period the profit will increase.

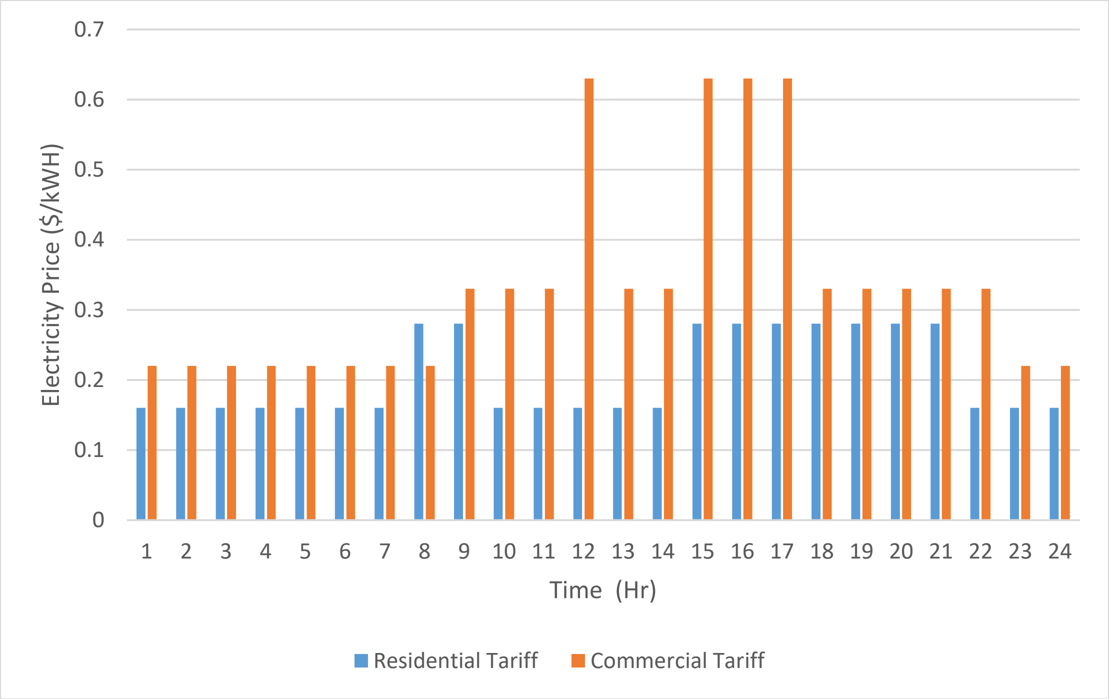


Figure 3.5: Residential and Commercial electricity tariff

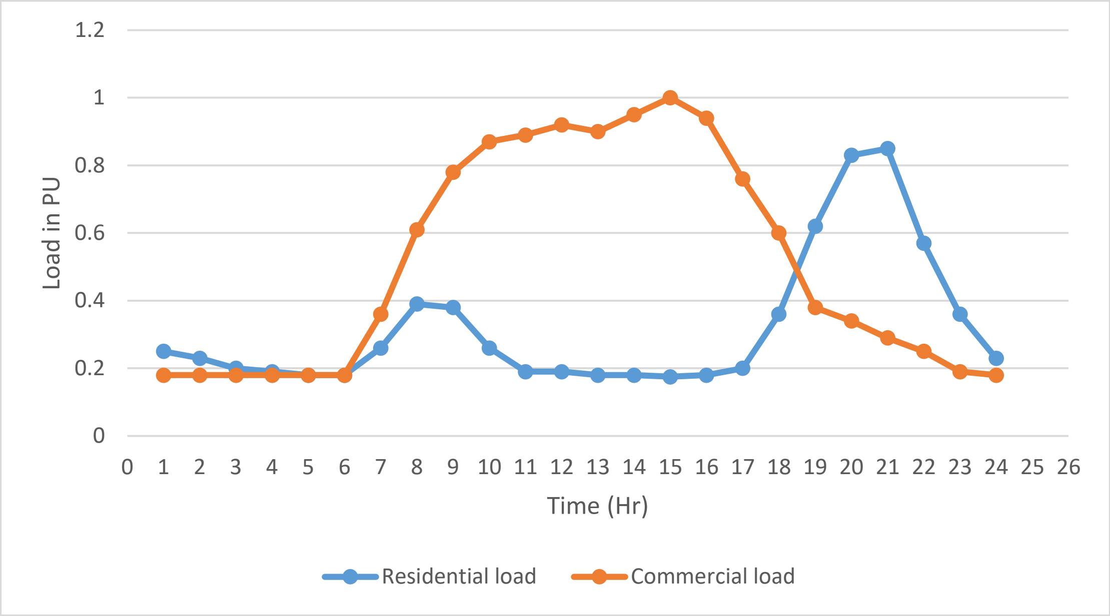


Figure 3.6: Residential and Commercial Load pattern

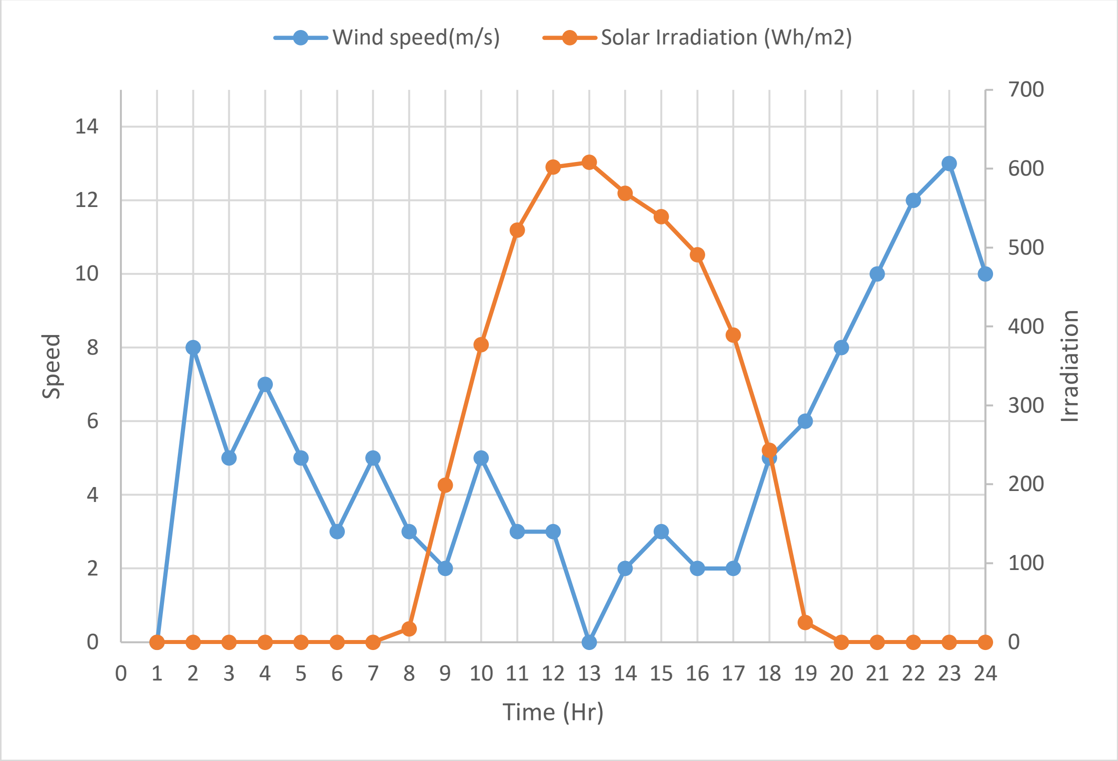


Figure 3.7: Solar and Wind Power at each hour of a day

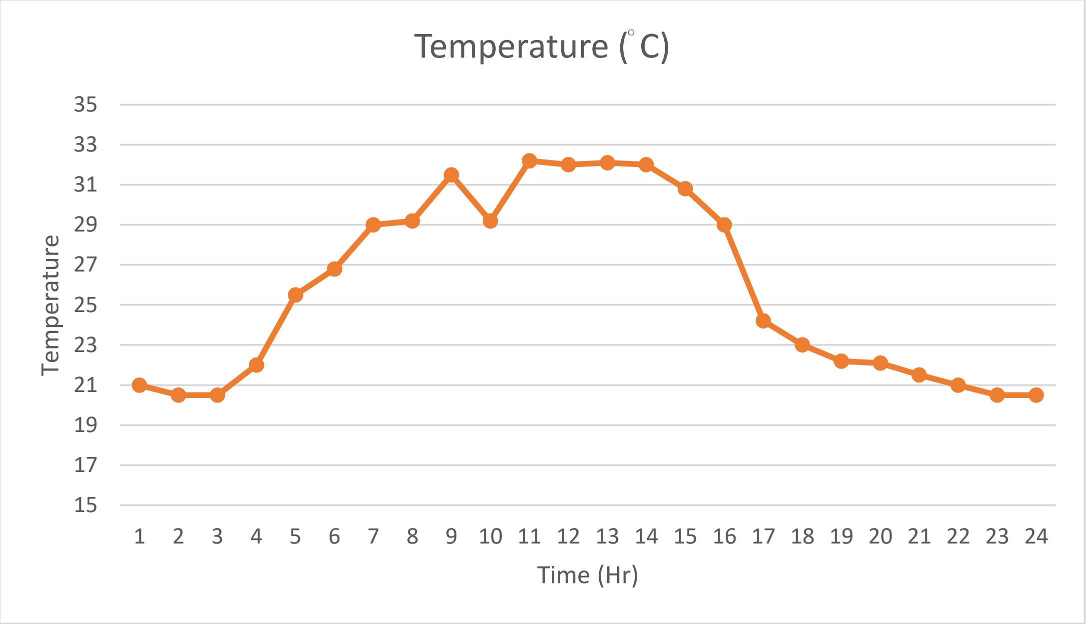


Figure 3.8: Temperature at Different Hours of a day

3.6 Tools and Software

MATLAB (MATrix LABoratory) is a software that makes the calculation in the form of matrix. It can compute the complex mathematical equations within the short period of time. This software can perform multiple number of functions such as simulation of electrical, mechanical, electronics, biological system. PID tuning, load flow analysis, fault analysis, etc. are some of the important functions within electrical engineering that can be performed in this software. This research work is carried out in MATLAB (R2016a) and run on computer with 2.1 GHz Core2Duo processor with 4 GB RAM.

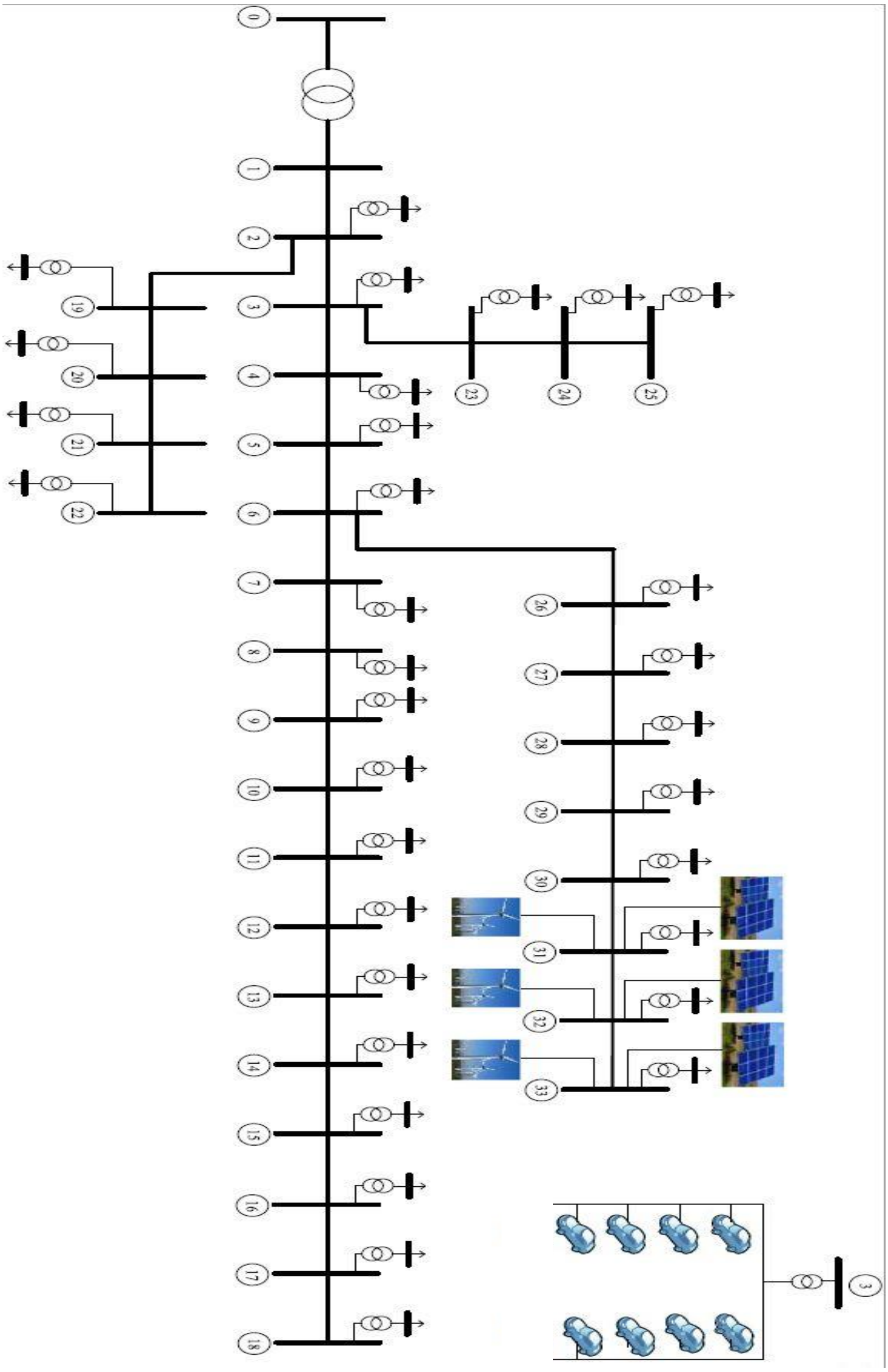


Figure 3.9 Bus Distribution System

CHAPTER FOUR: RESULT AND DISCUSSION

4.1 IEEE 15 Bus System

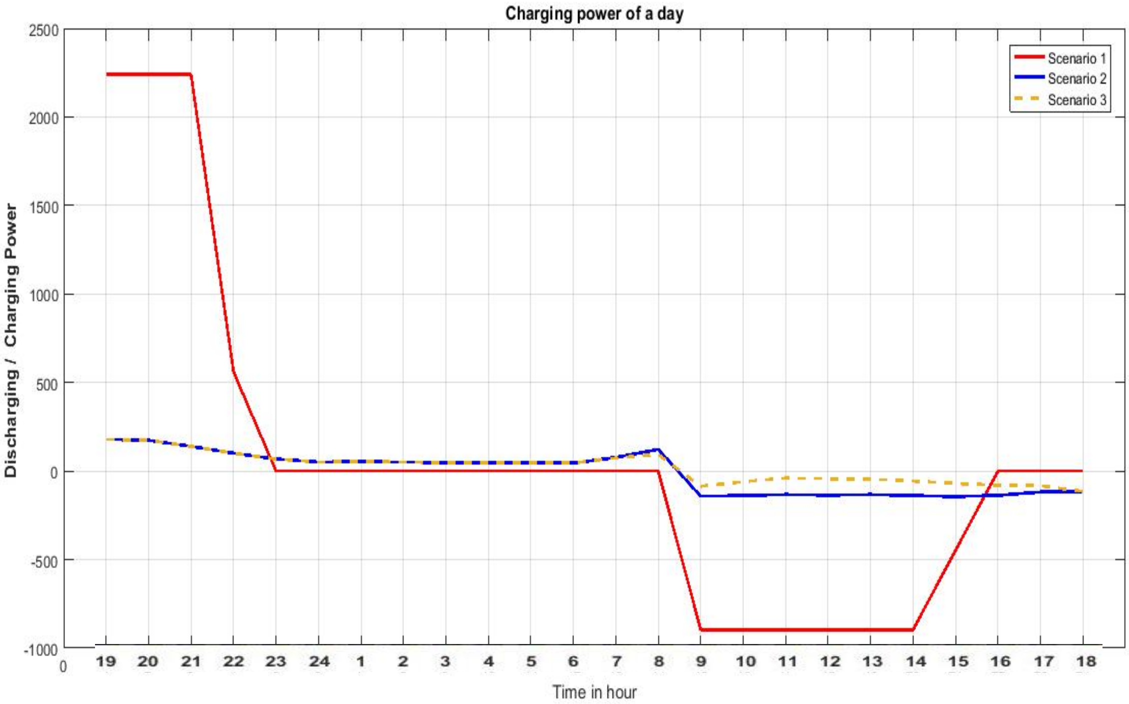


Figure 4.1: Charging and Discharging Power in Three Different Scenarios

Figure 4.1 represents the graph showing charging and discharging behavior of EV during different hours of day for three different scenarios. Here time is set to begin from 19:00 considering it to be the time when all EVs return home and chargers are plugged in. Scenario 1, 2 and 3 are represented by red, blue and dotted yellow line respectively.

At scenario 1, results shows that due to uncoordinated charging, all EVs gets charged at maximum charging capacity of 20 kW as soon as they reach home for almost 3 hours and then decreases slowly to zero. EV remains idle till eight in the morning and then discharge power during period of 8 am to 4 pm during which commercial tariff is high. During this time, the EVs are discharged at their rated capacity i.e. 8 KW to the grid. The profit is highest during this period. But discharging battery in this way will have high depth of discharge leading to increase in battery degradation cost. Since there are eight EVs each drawing 20 KW in all the buses except bus no. 1, thus the total EV charging power at 19:00 is 2240 KW. Charging the EVs in this way leads to overloading of the grid increasing the losses and low voltage profile, voltage instability and then blackout. Scenario 1 acts as a base case for the other two scenarios.

In scenario 2, EVs are charged and discharged in a controlled way. Once the EVs are plugged into the distribution network, the algorithm analyses the network parameters such as renewable power availability, residential and commercial load, etc. and tries to minimize the overall cost of the system. The cost includes cost due to losses, residential cost, commercial cost, and cost due to EV charging. The algorithm determines the optimum charging or discharging power which will be used in the load flow analysis to calculate the voltage profile of the system and the system losses. The EVs are charged at the optimal value maintaining the voltage of the weakest bus is maintained at 0.94 pu. Charging this way has reduced the losses of the system significantly maintaining the network stability. Once the EV is plugged in, charging power is very less which is around 1.8 kW which reduces after few hours after maintaining the battery SOC to some significant value. EVs are discharged during high tariff period similar to scenario 1 but in a controlled way. Discharging battery this way reduces the battery degradation cost increasing lifetime of the battery. Also the tariff is highest during hour 12:00, 15:00, 16:00, and 17:00 hour so, discharging batteries during this period help user to earn highest profit. Unlike scenario 1 where the EV is fully discharged at hour 15:00 and couldn’t sell energy in hour 16 and 17, in scenario 2 EV users can sell energy in all the four hours of high tariff period increasing the profit than in scenario 1.

Scenario 3 is similar to that of scenario 2 except that in this scenario renewables are integrated into the system. The power from the wind depends on wind speed and power from wind turbine is zero below the cut in speed and above the cut out speed. The power from the wind turbine is fluctuating throughout the day and likewise power from solar PV is high during day time as shown in figure 3.7. Three set of wind turbines and solar PVs are installed at each bus except bus no 1 in scenario 3. Firefly Algorithm is used to determine the optimum value of the charging and discharging power for the EVs similar to that of scenario 2.

Once the EVs are plugged into the network, they are charged at very slow rate as in scenario 2. Similarly during the day time when commercial tariff is high, discharging of the battery occurs to earn the maximum profit like in case of scenario 1 and 2. The power discharged back to the grid from EVs in scenario 3 has decreased in this case as deficiency of power during peak hour is partially fulfilled by penetration of renewable energy sources. During day time solar PV generates maximum power i.e. grid has almost enough amount of power so power discharging from EVs to grid has to slow down otherwise it might lead to instability of the system due to over voltage and over frequency. Thus in order to maintain the system stability the EVs are discharged at lower power during this time. Since power discharged from EVs to grid is less profit earned by EV user is lower but battery life cycle has increased than that in scenario 2.

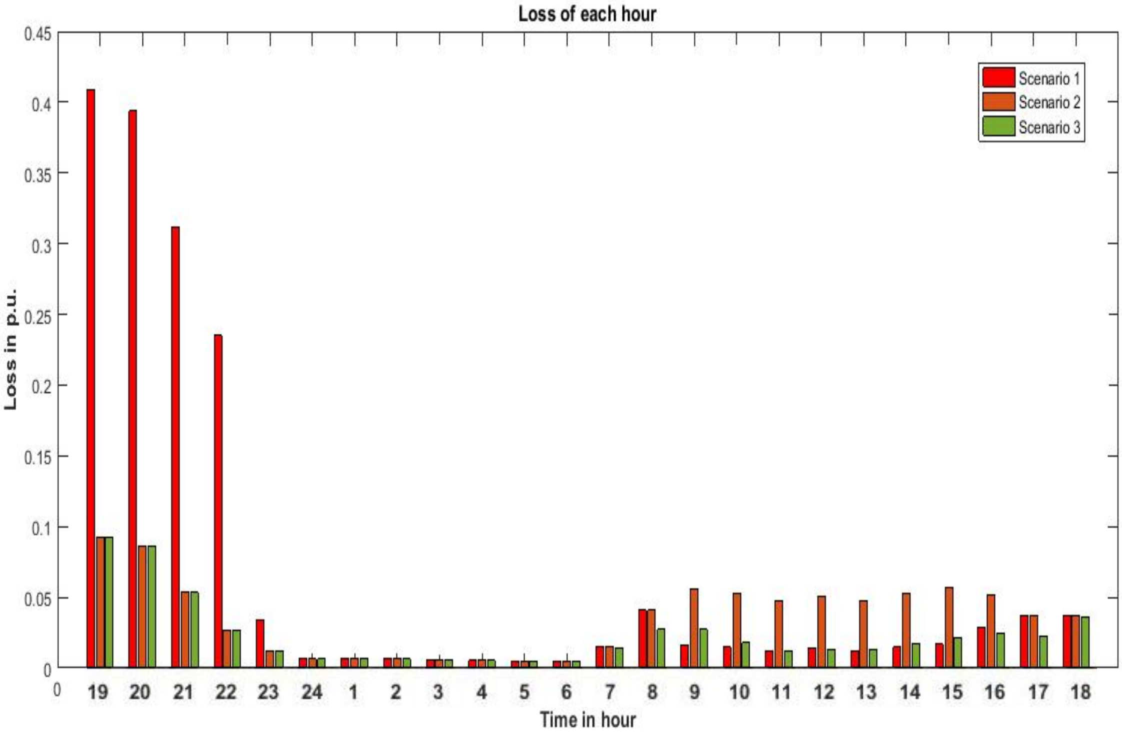


Figure 4.2: Hourly Loss of System for three different scenarios

Figure 4.2 shows losses of the system at each hour of a day for three different scenario. The losses are high during the charging but once they are fully charged the losses are in the normal value. It can be seen during uncoordinated charging i.e. in case of scenario 1 losses are very high compared to scenario 2 and 3.

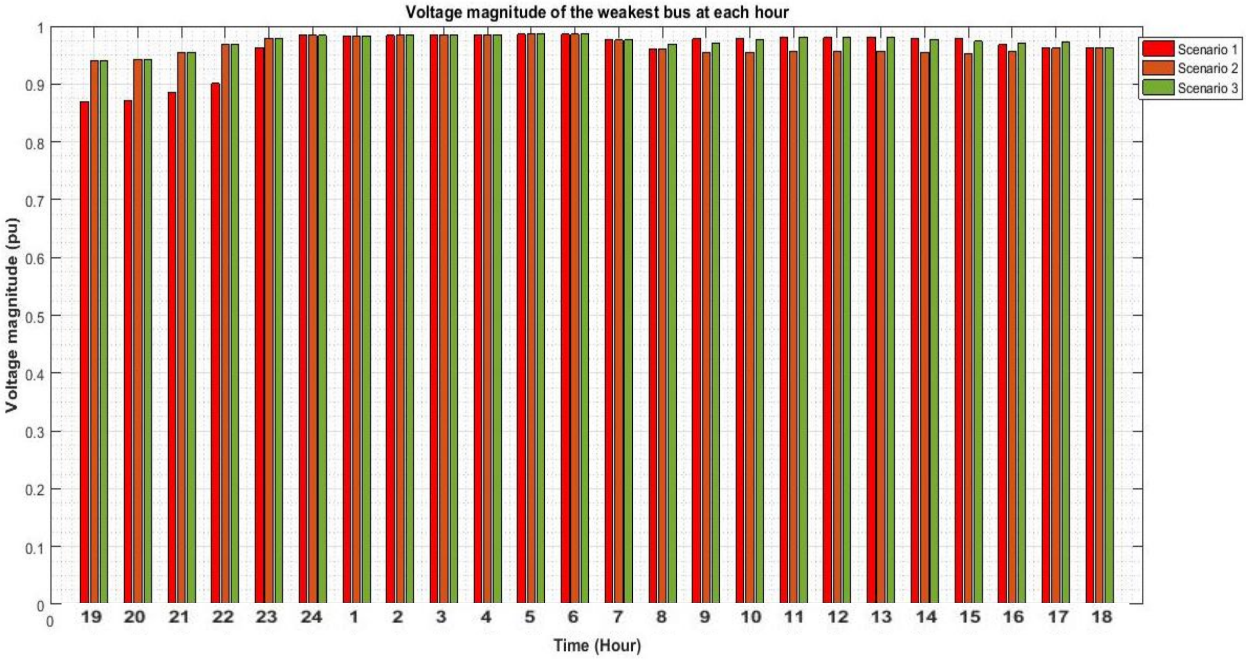


Figure 4.3: Voltage Magnitude for the Weakest Bus for three scenarios

Figure 4.3 represents the voltage magnitude for the weakest bus in IEEE 15 bus system at three scenarios during different hours of day. It can be seen that in scenario 1 during fast charging time voltage magnitude is less than the minimum value limit i.e. 0.94 pu thus making system unstable and low voltage profile. Due to use of algorithm voltage in case of scenario 2 and 3 are maintained between 0.94 to 1pu.

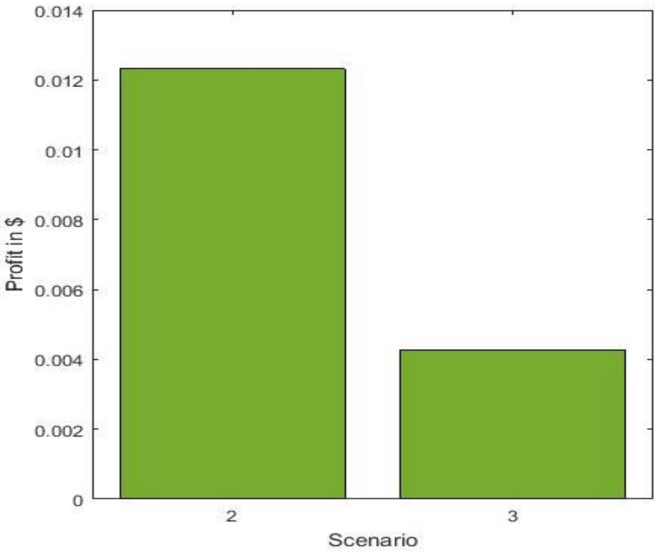


Figure 4.4: Profit to each EV user at different Scenario

Figure 4.4 represents the profit made by EV users at scenario 2 and 3 that is during coordinated charging and discharging but with and without penetrating renewables into the system. Profit made is higher in scenario 2 because power discharged back to grid in case of scenario 2 is higher than that in scenario 3.

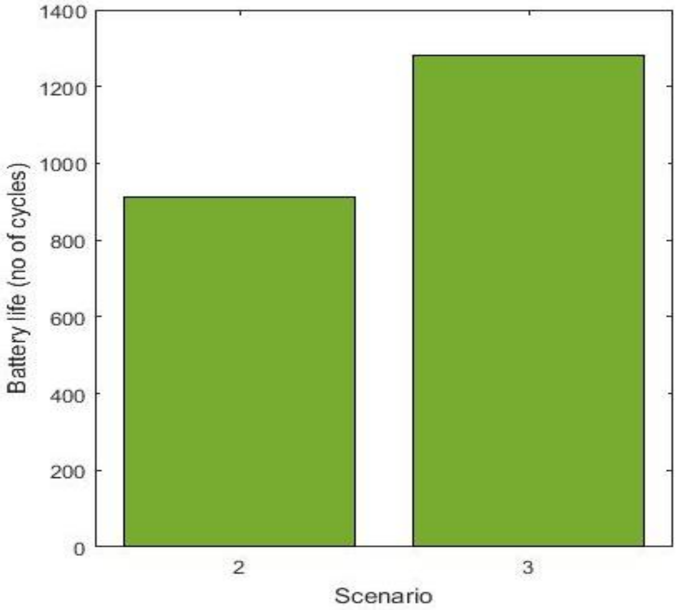


Figure 4.5: Battery Life cycle for two different scenario

Figure 4.5 represents the battery life cycle at scenario 2 and 3. Though profit made is higher at scenario 2, battery life cycle is lower than that in scenario 3. Therefore penetrating renewables in system results in lesser profit made but has increased lifecycle of battery.

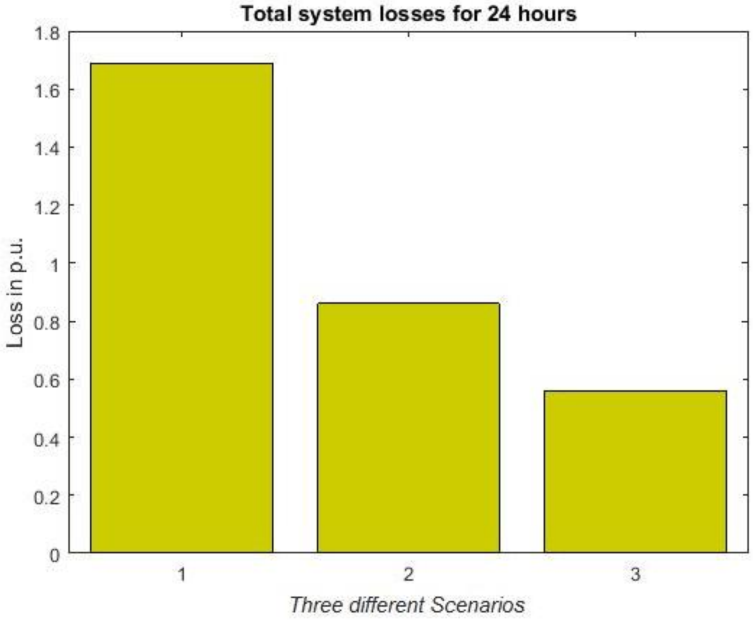


Figure 4.6: Total System Losses for three different Scenarios

Figure 4.6 represent total system losses in three scenarios. It can be seen that losses during uncoordinated charging and discharging is almost double and four times that in case of scenario 2 and 3 respectively. It can be seen system loss is very low when system is operated in presence of renewables.

4.2 Real Feeder (Khumaltar Feeder)

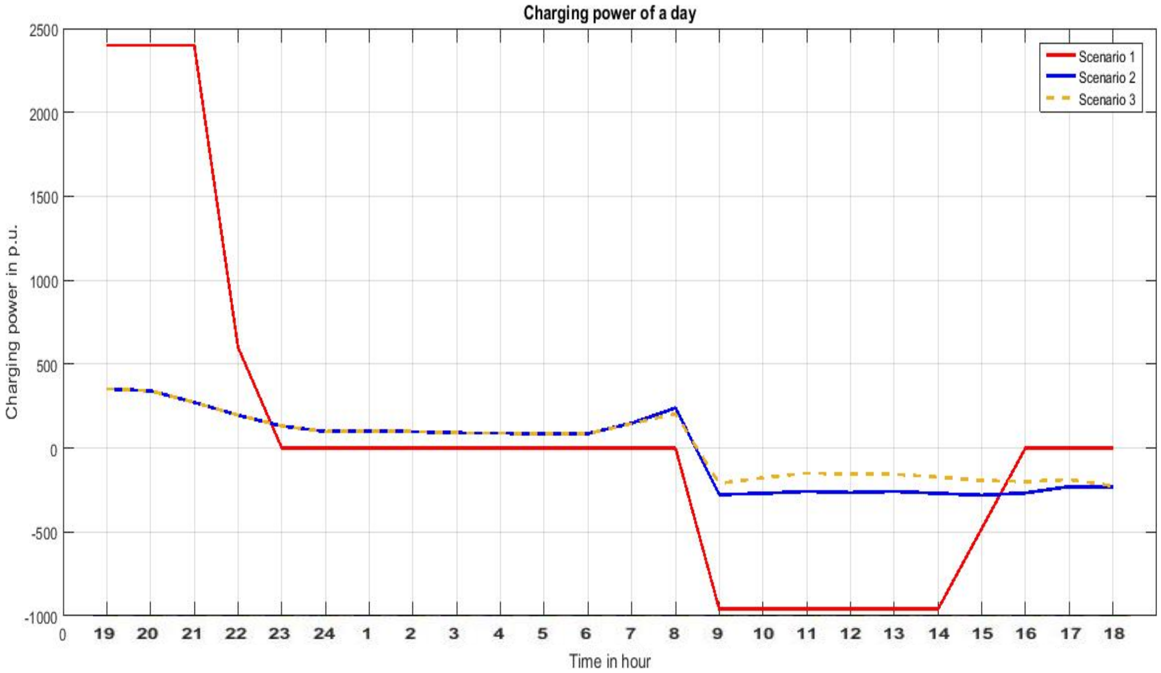


Figure 4.7: Charging and Discharging Power in Three Different Scenarios

Figure 4.7 represents the graph showing charging and discharging behavior of EV during different hours of day for three different scenarios for a real system. Results obtained for the Khumaltar feeder, a real system is similar to that of IEEE 15 bus test bus. Like in case of tese bus, time is set to begin from 19:00 hours considering it to be the time when all EVs return home and chargers are plugged in. Scenario 1, 2 and 3 are represented by red, blue and dotted yellow line respectively.

At scenario 1, results shows that due to uncoordinated charging, all EVs gets charged at maximum charging capacity of 20 kW as soon as they reach home for almost 3 hours and then decreases slowly to zero. EV remains idle till eight in the morning and then discharge power during period of 8 am to 4 pm during which commercial tariff is high. During this time, the EVs are discharged at their rated capacity i.e. 8 KW to the grid. The profit is highest during this period. But discharging battery in this way will have high depth of discharge leading to increase in battery degradation cost. Since there are eight EVs each drawing 20 KW in all the buses except bus no. 1, thus the total EV charging power at 19:00 is 2400 kW. Charging the EVs in this way leads to overloading of the grid increasing the losses and low voltage profile, voltage instability and then blackout. Scenario 1 acts as a base case for the other two scenarios.

In scenario 2, EVs are charged and discharged in a controlled way. Once the EVs are plugged into the distribution network, the algorithm analyses the network parameters such as renewable power availability, residential and commercial load, etc. and tries to minimize the overall cost of the system. The cost includes cost due to losses, residential cost, commercial cost, and cost due to EV charging. The algorithm determines the optimum charging or discharging power which will be used in the load flow analysis to calculate the voltage profile of the system and the system losses. The EVs are charged at the optimal value maintaining the voltage of the weakest bus is maintained at 0.94 pu. Charging this way has reduced the losses of the system significantly maintaining the network stability. Once the EV is plugged in, charging power is very less and charging period lasts throughout the night tile 8 in the morning maintaining battery SOC to some significant value. EVs are discharged during high tariff period similar to scenario 1 but in a controlled way. Discharging battery this way reduces the battery degradation cost increasing lifetime of the battery. Also the tariff is highest during hour 12:00, 15:00, 16:00, and 17:00 hour so, discharging batteries during this period help user to earn highest profit. Unlike scenario 1 where the EV is fully discharged at hour 15:00 and couldn’t sell energy in hour 16 and 17, in scenario 2 EV users can sell energy in all the four hours of high tariff period increasing the profit than in scenario 1.

Scenario 3 is similar to that of scenario 2 except that in this scenario renewables are integrated into the system. The power from the wind depends on wind speed and power from wind turbine is zero below the cut in speed and above the cut out speed. The power from the wind turbine is fluctuating throughout the day and likewise power from solar PV is high during day time as shown in figure 3.7. In order to bring practicality to the real system, the system is integrated only with the solar panels. The wind turbines is not integrated into the system because wind power generation in Kathmandu is not practically feasible. Three sets of solar PVs are installed at each bus except bus no 1 in scenario 3. Firefly Algorithm is used to determine the optimum value of the charging and discharging power for the EVs similar to that of scenario 2.

Once the EVs are plugged into the network, they are charged at very slow rate as in scenario 2. Similarly during day time when commercial tariff rate is high, discharging of battery occurs to earn the maximum profit like in case of scenario 1 and 2. The power discharged back to the grid from EVs in scenario 3 has decreased in this case as deficiency of power during peak hour is partially fulfilled by penetration of renewable energy sources. During day time solar PV generates maximum power i.e. grid has almost enough amount of power so power discharging from EVs to grid has to slow down otherwise it might lead to instability of the system due to over voltage and over frequency. Thus in order to maintain the system stability the EVs are discharged at lower power during this time. Since power discharged from EVs to grid is less profit earned by EV user is lower but battery life cycle has increased than that in scenario 2.

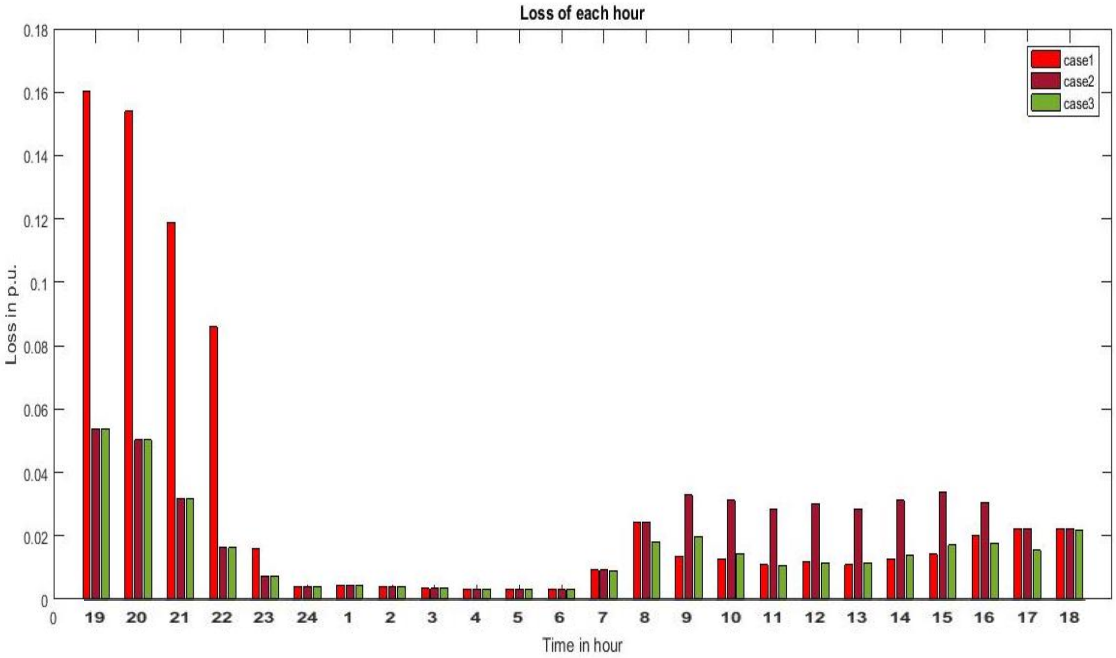


Figure 4.8: Hourly Loss of System for Three different Scenarios

Figure 4.8 shows losses of the system at each hour of a day for three different scenario. The losses are high during the charging but once they are fully charged the losses are in the normal value. It can be seen during uncoordinated charging i.e. in case of scenario 1 losses are very high compared to scenario 2 and 3.

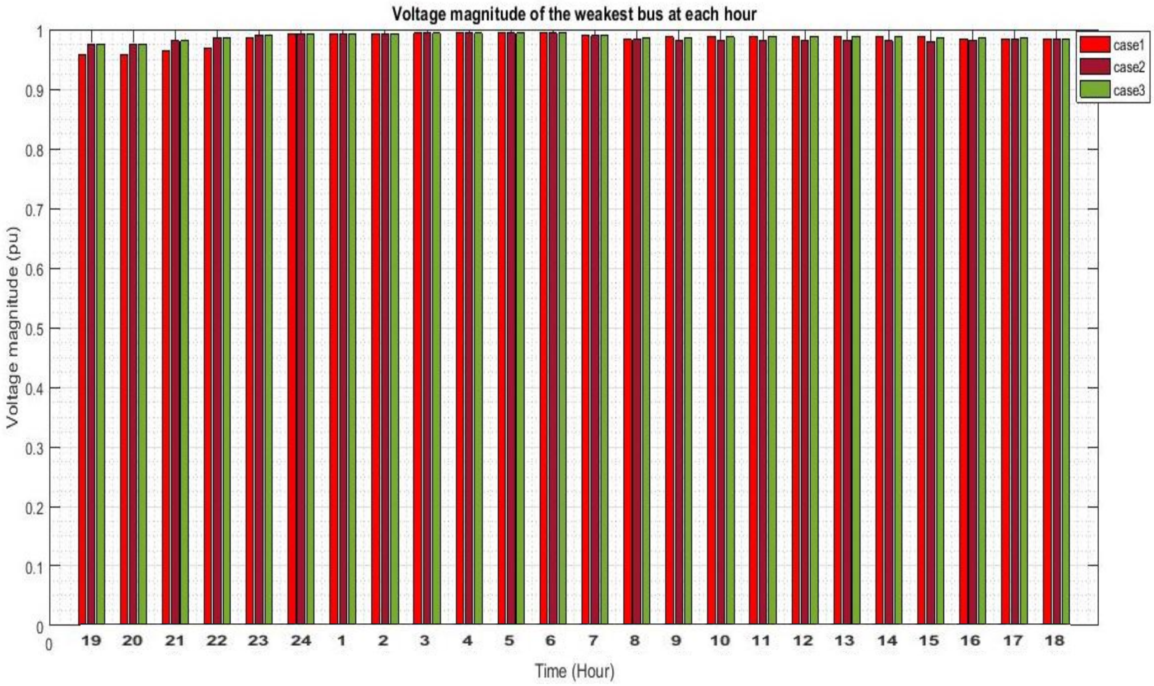


Figure 4.9: Voltage Magnitude for the Weakest Bus for three Scenarios

Figure 4.9 represents the voltage magnitude for the weakest bus in Khumaltar 16 bus real system at three scenarios during different hours of day. It can be seen that in scenario 1 during fast charging time voltage magnitude is less than the minimum value limit i.e. 0.94 pu thus making system unstable and low voltage profile. Due to use of algorithm voltage in case of scenario 2 and 3 are maintained between 0.94 to 1pu.

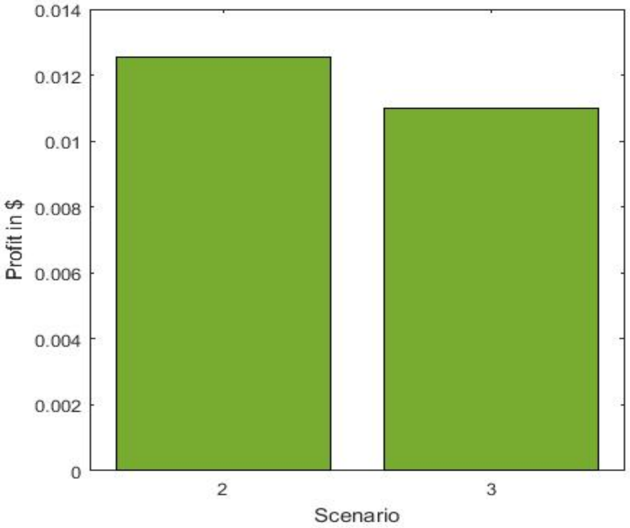


Figure 4.10: Profit to each EV user at different Scenario

Figure 4.10 represents the profit made by EV users at scenario 2 and 3 that is during coordinated charging and discharging but with and without penetrating renewables into the system. Profit made is higher in scenario 2 because power discharged back to grid in case of scenario 2 is higher than that in scenario 3.

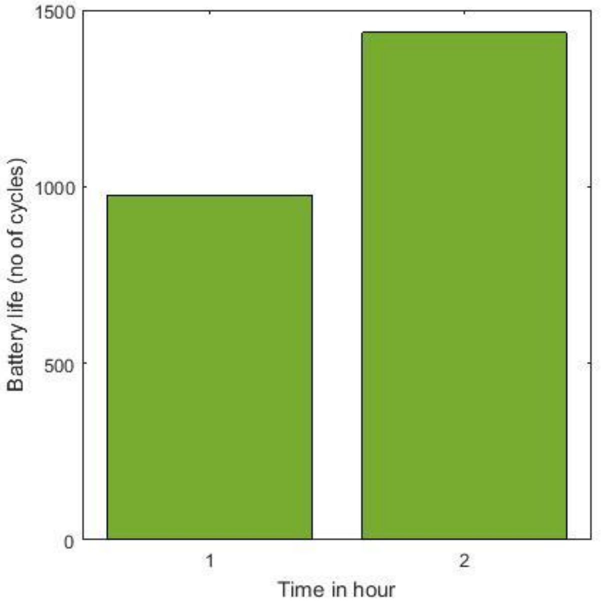


Figure 4.11: Battery Life for two different Scenario

Figure 4.11 represents the battery life cycle at scenario 2 and 3. Though profit made is higher at scenario 2, battery life cycle is lower than that in scenario 3. Therefore penetrating renewables in system results in lesser profit made but has increased lifecycle of battery.

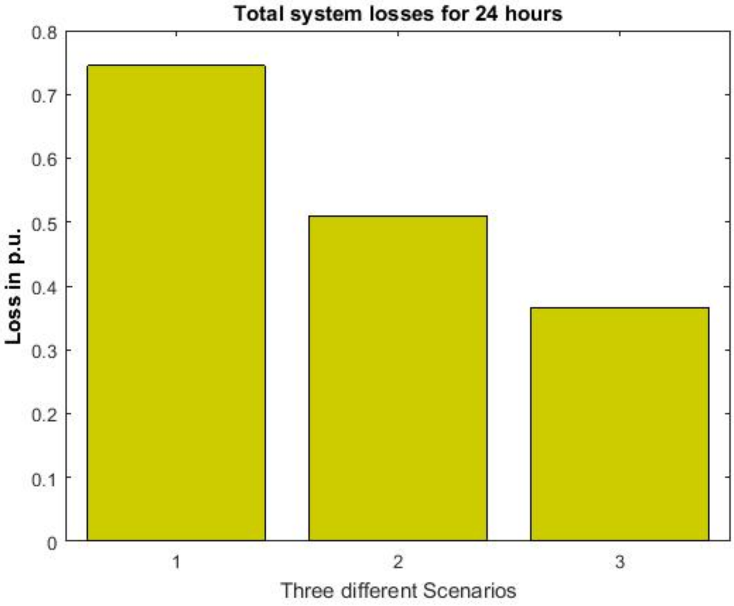


Figure 4.12: Total System Losses for three different Scenarios

Figure 4.12 represent total system losses in three scenarios. It can be seen that losses during uncoordinated charging and discharging is more than that in case of scenario 2 and 3 respectively. It can be seen system loss is very low when system is operated in presence of renewables that is in case of scenario 3.

CHAPTER FIVE: CONCLUSION

In scenario 1, when the EV is charged in uncontrolled manner after reaching home, it affected the system. Vehicle is discharged during time when tariff rate is high. Though it increases the profit made by EV user, lifecycle of the battery is highly affected due to high depth of discharge. This leads to situation where battery degradation cost is high. The voltage magnitude of weakest bus in the system is below minimum threshold limit i.e. 0.94 p.u. and losses are also very high. This might lead to the system instability and then to system blackout situation. The result is same for both the Khumaltar feeder a real system and the IEEE 15 BUS test bus.

In scenario 2, EV is charged and discharged in a controlled manner. The voltage of the buses are within limit for this scenario i.e 0.94 pu to 1 pu. The losses are low compared to scenario 1 and EV users earn good profit by selling the energy to the grid. The charging and discharging time is similar to scenario 1 but is done in a controlled way. Charging of EV is done throughout the night time decreasing burden to grid during the peak hour period in the evening. System loss is lower with better voltage profile compared to base case scenario i.e. scenario 1, increasing stability and resiliency of system. Since number of buses and their loading is different for Khumaltar feeder and IEEE 15 bus system, there is difference in total charging power and also number of EV connected differs. In addition to it, losses of the system at each hour and the total system losses are also different for the real and test system

Scenario 3 similar to scenario 2 except there are renewables integrated into the system in scenario 3. In this scenario, charging and discharging pattern of the EV is similar to scenario 2. During the day time when the power output from the renewables are high, EVs are charged in both real feeder and test bus system. EV is not charged as soon as reaching home like in previous cases but instead discharged during peak hour period when power from renewables injected is low. The vehicle is charged when power from renewables is high in system. Though profit made by EV users is low, overall performance of the system is better compared to the previous two scenarios. Also the battery lifecycle is better in scenario 3 than that of scenario 2. Results for both Khumlatar feeder and IEEE15 bus system is similar in scenario 1 and 2 but there is minor variation in case of scenario 3. Variation is due to absence of wind power source in case of the real system as wind power is not feasible in Kathmandu valley.

In test bus system, there availability of power from wind turbine along with solar PV. But in case of real system, power from wind turbine has been eliminated i.e. only solar is available and power from renewables is low in real system than in test bus. Thus charging power of real system during this period is low than in test system. The total system losses of test system is higher compared to real feeder system because power flow is higher in test bus due to presence of renewables. Battery lifecycle for this scenario is better than scenario 2 because of the reduced depth of discharge of battery. For real system battery lifecycle is higher than that of test system because discharging of battery is less i.e. depth of discharge of the battery strained to safe limit. Though profit for each EV user is lower in case of scenario 3 compared to scenario 2, EV battery life is higher and losses are lower. Scenario 3 has better voltage profile, low losses, increased battery life cycle compared to earlier two scenarios.

Thus, it can concluded from output data shown in results that scenario 3 is best case scenario i.e. charging and discharging of EV in presence of renewables in the system is best for both EV users and grid.

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ANNEXES

Annex 1: Parameter of EV

Component Parameter	Value
Capacity of Battery (KWh)	85
SOC min/max limit (%)	20 / 100
$P_{ch}^{ev}{}_{,max}$ (KW)	20
$P_{dch}^{ev}{}_{,max}$ (KW)	8
Efficiency	0.9

Annex 2: Solar irradiation and temperature of a day

Time (hour)	Solar Irradiation (Wh/m^2)	Temperature (^{0}C)
1	0	21
2	0	20.5
3	0	20.5
4	0	22
5	0	25.5
6	0	26.8
7	17	29
8	199	29.2
9	377	31.5
10	522	29.2
11	602	32.2
12	608	32
13	569	32.1
14	539	32
15	491	30.8
16	389	29
17	243	24.2
18	25	23
19	0	22.2
20	0	22.1
21	0	21.5
22	0	21
23	0	20.5
24	0	20.5

Annex 3: Wind Speed and Temperature of Day

Time (hour)	Wind speed(m/s)	Temperature (^{0}C)
1	8	21
2	5	20.5
3	7	20.5
4	5	22
5	3	25.5
6	5	26.8
7	3	29
8	2	29.2
9	5	31.5
10	3	29.2
11	3	32.2
12	0	32
13	2	32.1
14	3	32
15	2	30.8
16	2	29
17	5	24.2
18	6	23
19	8	22.2
20	10	22.1
21	12	21.5
22	13	21
23	10	20.5
24	9	20.5

Annex 4 IEEE 33 bus data

Branch No.	From Bus	To Bus	R Ohm	X Ohm	Load at Bus	
					P(kW)	**Q(kVar)**
1	1	2	0.0922	0.047	0	0
2	2	3	0.493	0.2511	100	60
3	3	4	0.366	0.1864	90	40
4	4	5	0.3811	0.1941	120	80
5	5	6	0.819	0.707	60	30
6	6	7	0.1872	0.6188	60	20
7	7	8	1.7114	1.2351	200	100
8	8	9	1.03	0.74	200	100
9	9	10	1.044	0.74	60	20
10	10	11	0.1966	0.065	60	20
11	11	12	0.3744	0.1238	45	30
12	12	13	1.468	1.155	60	35
13	13	14	0.5416	0.7129	60	35
14	14	15	0.591	0.526	120	80
15	15	16	0.7463	0.545	60	10
16	16	17	1.289	1.721	60	20
17	17	18	0.732	0.574	60	20
18	2	19	0.164	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	3	23	0.4512	0.3	90	40
23	23	24	0.898	0.7091	90	40
24	24	25	0.896	0.7011	420	40
25	6	26	0.203	0.1034	420	200
26	26	27	0.2842	0.1447	60	25
27	27	28	1.059	0.9337	60	25
28	28	29	0.8042	0.7006	60	20
29	29	30	0.5075	0.2585	120	70
30	30	31	0.9744	0.963	200	600
31	31	32	0.3105	0.3619	150	70
32	32	33	0.341	0.5302	210	100

Annex 5: Residential and Commercial load for a day

Time (hour)	Residential load	Commercial load
1	0.25	0.18
2	0.23	0.18
3	0.2	0.18
4	0.19	0.18
5	0.18	0.18
6	0.18	0.18
7	0.26	0.36
8	0.39	0.61
9	0.38	0.78
10	0.26	0.87
11	0.19	0.89
12	0.19	0.92
13	0.18	0.9
14	0.18	0.95
15	0.175	1
16	0.18	0.94
17	0.2	0.76
18	0.36	0.6
19	0.62	0.38
20	0.83	0.34
21	0.85	0.29
22	0.57	0.25
23	0.36	0.19
24	0.23	0.18

Annex 6: Residential and Commercial Tariff for a day

Hour	Residential Tariff	Commercial Tariff
1	0.16	0.22
2	0.16	0.22
3	0.16	0.22
4	0.16	0.22
5	0.16	0.22
6	0.16	0.22
7	0.16	0.22
8	0.28	0.22
9	0.28	0.33
10	0.16	0.33
11	0.16	0.33
12	0.16	0.63
13	0.16	0.33
14	0.16	0.33
15	0.28	0.63
16	0.28	0.63
17	0.28	0.63
18	0.28	0.33
19	0.28	0.33
20	0.28	0.33
21	0.28	0.33
22	0.16	0.33
23	0.16	0.22
24	0.16	0.22

Annex 7: Khumaltar Feeder Data

Branch No.	From Bus	To Bus	R (Ω)	X (Ω)	Load KVA	Active Power kW	Reactive Power kVar
1	Patan Substation (1)	Lagankhel Army Camp(2)	0.14	0.15	100	80	60
2	Lagankhel Army Camp(2)	Chapagaun Dobato Bhatbhateni (3)	0.21	0.22	100	80	60
3	Chapagaun Dobato Bhatbhateni (3)	Satdobato Aankashe Pul (4)	0.07	0.08	200	160	120
4	Satdobato Aankashe Pul (4)	Satdobato Chowk(5)	0.02	0.03	100	80	60
5	Chapagaun Dobato Bhatbhateni (3)	Tutepani J. school(6)	0.07	0.07	300	240	180
6	Tutepani J. school(6)	Ullens new building (7)	0.12	0.13	200	160	120
7	Ullens new building (7)	Ullens old building (8)	0.03	0.03	100	80	60
8	Ullens old building (8)	Ullens old ahead (9)	0.05	0.06	100	80	60
9	Ullens new building (7)	Sampang Chowk(10)	0.18	0.19	100	80	60
10	Sampang Chowk(10)	Annal Jyoti low(11)	0.07	0.07	200	160	120
11	Annal Jyoti low(11)	Mid Khumaltar dobato(12)	0.19	0.07	150	120	90
12	Mid Khumaltar dobato(12)	ICIMOD(13)	0.18	0.06	500	400	300
13	ICIMOD(13)	Khumaltar dobato(14)	0.09	0.03	100	80	60
14	Annal Jyoti low(11)	Dholahiti ukalo(15)	0.17	0.18	100	80	60
15	Dholahiti ukalo(15)	Dhapakhel Dobato(16)	0.73	0.78	150	120	90

Annex 8: IEEE 15 BUS Data

Branch No.	**Bus No.**		**Line data**		**Load data**	
	From	To	Resistance (Ohms)	Inductance (Henry)	Active Power (KW)	Reactive power (KVAR)
1	1	2	1.35309	1.32349	44. 1	44.99
2	2	3	1.17024	1.14464	70.1	71.44
3	3	4	0.84111	0.82271	40	142.82
4	4	5	1.52348	1.0276	44. 1	44.99
5	2	9	2.01317	1.3279	70	71.44
6	9	10	1.68671	1.1377	44.1	44.99
7	2	6	2.55727	1.7249	140	142.82
8	6	7	1.0882	0.734	140	142.82
9	6	8	1.25143	0.8441	70	71.414
10	3	11	1.79553	1.2111	140	142.82
11	11	12	2.44845	1.6515	70	71.414
12	12	13	2.01317	1.3579	44.1	44.99
13	4	14	2.23081	1.5047	70	71.414
14	4	15	1.9702	0.8074	140	142.82