

# **Coordinated system for charging and discharging for different and various electric vehicles for energy management**

*Report submitted to the SASTRA Deemed to be University  
as the requirement for the course*

## **EEE300: MINI PROJECT**

*Submitted by*

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THANJAVUR, TAMIL NADU, INDIA-613 401**



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**Bonafide Certificate**

This is to certify that the report titled "**Coordinated system for charging and discharging for different and various electric vehicles for energy management**" submitted as a requirement for the course, **EEE300: MINI PROJECT** for B. Tech. Electrical & Electronics Engineering programme, is a bonafide record of the work done by **Ms. Mithra Vinda Reddy K (Reg.No.123005085)**, **Mr. Sarvesh Babu R G (Reg.No.123005132)**, **Ms. Shwetha S (Reg.No.123005140)** during the academic year 2022-23, in the **School of Electrical and Electronics Engineering**, under my supervision.

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**Date : 06 / 12 / 2022**

Project *Vivavoce* held on

**Examiner-I**

**Examiner-II**



# SASTRA

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## SCHOOL OF ELECTRICAL & ELECTRONICS ENGINEERING THANJAVUR-613 401

### Declaration

We declare that the report titled "**Coordinated system for charging and discharging for different and various electric vehicles for energy management**" submitted by me/us is an original work done by us under the guidance of **Dr. Narayanan K, SAP, School of Electrical and Electronics Engineering, SASTRA Deemed to be University** during the academic year 2022-23, in the **School of Electrical and Electronics Engineering**. The work is original and wherever We have used materials from other sources, I/We have given due credit and cited them in the text of the report. This report has not formed the basis for the award of any degree, diploma, associate-ship, fellowship or other similar title to any candidate of any University.

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# **ABSTRACT**

This work proposes a method for charging and discharging the batteries in Electric Vehicles (EV). The classification of Electric vehicles is Private Vehicle, Commercial Vehicle, Emergency Vehicle, VIP Vehicle based on the battery capacity and vehicle's usage.

The State of Charge (SoC) of each vehicle is calculated for every twenty minutes and compared with the threshold limits of SoC. The Distance traveled and the time for which it is connected to the grid is fixed for each vehicle type. The ideal pattern has been established by comparing the charging pattern with the scheduled Real Time Pricing (RTP) for every 20-minute block. Here 20-minute blocks are considered because the time required for full charge varies from vehicle to vehicle. The pattern has been formulated in such a way that discharging occurs when the cost is higher (peak hours), charging occurs when the cost is low (off peak hours). Few blocks are left idle when charging or discharging is not feasible because of violation of threshold limits. The total price has been calculated for each vehicle for a span of 24 hours after the charging and discharging patterns are established.

The novelty of this work is the establishment of a travel pattern for the classified types of vehicles and thereby arriving at the best charging/discharging patterns.

## **Specific Contribution**

- Establishing the travel pattern for the classified vehicles by using the vehicle's battery capacity and how much time it takes to complete its trip.

## **Specific Learning**

- Understood about various ranges of battery capacities of the vehicles and time to complete its trip after one time charging.

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# **ABSTRACT**

This work proposes a method for charging and discharging the batteries in Electric Vehicles (EV). The classification of Electric vehicles is Private Vehicle, Commercial Vehicle, Emergency Vehicle, VIP Vehicle based on the battery capacity and vehicle's usage.

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The novelty of this work is the establishment of a travel pattern for the classified types of vehicles and thereby arriving at the best charging/discharging patterns.

## **Specific Contribution**

- Charging/Discharging Pattern formulation for the classified Electric Vehicles by comparing it with the Real time pricing.

## **Specific Learning**

- Understood about various types of Electric Vehicles, time required for them to charge and discharge.
- Understood about Real Time Pricing (RTP) and its benefits when incorporated with charging schemes.

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The novelty of this work is the establishment of a travel pattern for the classified types of vehicles and thereby arriving at the best charging/discharging patterns.

## **Specific Contribution**

- The vehicles have been classified into different categories based on the usage and the battery capacity. The classifications are Private Vehicle, Commercial Vehicle, Emergency Vehicle, VIP Vehicle.

## **Specific Learning**

- Understood about Electric Vehicles and its parameters like Charging, Discharging and State of charge.
- Understood that Electric vehicles have different battery capacity and time required for full charge depends on the type of vehicle.

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## **ABBREVIATIONS**

<b>EV</b>	Electric Vehicle
<b>RTP</b>	Real Time Price

## NOTATIONS

$SoC_{(y)}$	State of Charge in present hour
$SoC_{(y-1)}$	State of Charge in previous hour
$\eta_c$	Charging Efficiency
$\eta_d$	Discharging Efficiency
$\partial y$	Time Interval
$SoC_{Threshold}$	Threshold limit for State of Charge
$Ch_t$	Energy delivered at time ‘t’
$Rtp$	Real Time Price Array
$T_n$	Cost of ‘ $n^{th}$ ’ iteration

# **CHAPTER 1**

## **INTRODUCTION**

With the increase in Pollution , fuel demand, global warming and many other socio-economic issues, one could say Electric Vehicles(EV) will be the future means of transport. Electric Vehicles have the potential to reshape the transportation sector, drastically cutting carbon emissions and clearing the way for significant climate progress.

EVs help to conserve non-renewable natural resources. Due to this the import of natural gasses and the dependency of a nation on petroleum export countries will be reduced. When compared to the recurring expenditure on natural gasses, the cost of EVs are low. The maintenance of electric motors is less when compared with traditional non- electric motors. Electric vehicles have different methods for conversion of fuel to electricity.

Electric bikes, Cars, rickshaws, trucks, etc are some examples of EVs. Most of the trains including metros are already running through electricity all over the world, but there is a problem in charging EVs in comparison with the motor vehicles EVs can't be charged instantly like Petrol/Diesel Vehicles. So here there is a need for an effective charging scheme.

But in present times there are difficulties based on how to charge EVs when there is higher load demand. The problem arises when there are many vehicles at the same time to charge and prioritize them accordingly, there are lesser number of charging stations and the charging time of vehicles differs for different vehicles. Replacement of battery packs can be one such solution but that is quite expensive for people to afford. Charging EVs will have a significant impact on the power grid. In order to manage EVs charging, there is a need for an intelligent charging strategy that supports EVs charging while preventing the power grid from overloading. Charging/discharging pattern scheme using Real Time Price can be one possible solution for the difficulties mentioned above and the same is discussed below.

Today when advancement of technology is growing rapidly EVs are the new means of transport to fulfill the larger demand of people growing day by day.

One more important factor to consider regarding EVs is the cost of electricity. There are various types of tariffs followed by the government depending on various factors like maximum demand, Time of the load, Type of the load, amount of the energy used, etc.

Real time price is one such system where the prices vary hourly and the consumer is charged a different price for each interval, here price solely depends on the demand in the network prevailing during the time. This benefits the consumers as well the government in cutting down their losses. Also, this system could make the load duration curve flatter.

The remainder of the thesis is organized as follows:

- A literature survey related to the work and the formulated objectives are presented in the chapter 2.
- The chapter 3 provides detailed explanation of methodology and the system model comprising of EV is presented in chapter 4.

- The chapter 4 deals with the mathematical modelling of the systems used.
- The chapter 5 consists of the results obtained for the considered test systems and are discussed and summarized.
- The conclusions of the work is presented in the chapter 6 with a brief description of the future scope of this work.

# CHAPTER 2

## LITERATURE SURVEY

Koundinya Sistla Pavan Venkat Sai et al. (2021) This paper addresses the problem of stability with the grid .The load profile of electric vehicle charging stations (EVCS) is determined and its impact of EVCS on the voltage profile of the distribution system. The principle of coordinated charging strategy is approached in this project to find the load profile of EVCS constrained by grid-to-vehicle (G2V) and vehicle-to-grid (V2G).

Chellappan et al. (2022) This paper focuses on minimization of the losses in the distribution network by the Distributed Generators (DGs) systems.The undesirable nature is one of the major challenges in maintaining the power between the DG and the grid. The battery energy storage system serves the purpose,supporting the grid by storing the energy in it. Sizing and placement of DG in the distribution system to support the grid and battery storage placed after the placement of the DGs is done in this work.Particle Swarm Optimization (PSO) is used for this purpose and for placement of the battery energy storage system a genetic algorithm is used in the IEEE networks such as IEEE-33, IEEE-69, IEEE-118 radial node distribution systems.This project incorporates the operation of the battery in accordance with the state of charge.

Senthilkumar et al. (2021) The paper focuses on Cost minimization and export maximisation by optimising the plug-in hybrid electric vehicle (PHEV) schedule , thereby reducing the import from the grid, subsequently minimising the overall operational cost. The proposed DR proposes to reduce imported electricity cost in peak hours by shifting the non-emergency loads(controllable loads) to off-peak hours.In this project the per hour Real time pricing(RTP) and load profile has been incorporated and analysed.

Lee et al. (2019) A dynamic EV charging dataset from the ACN data has been used as the reference to calculate the charging time, discharging time, kWh required, time required to full charge. With this data the charging-discharging pattern has been established.

Koundinya et al. (2020) This paper aims to establish a generalised procedure for evaluating the impact of Electric Vehicles Charging Stations (EVCS) on a distribution system. A load profile for 24 hours of EVCS is proposed using the travel patterns of EV .Radial Load Flow is performed on the distribution system.This is done when the EVCS is connected to the distribution system to find the voltage profile of the system. Voltage Stability Index (VSI) and Voltage Stability Factor (VSF) are calculated for the system with and without EVCS under many cases.

Rao et al. (2012) In this paper, an approach to reconfigure and install DG units simultaneously in the distribution system has been proposed which includes different loss reduction methods to establish the superiority of the proposed method. An effective meta heuristic HSA is used in the process of the network reconfiguration and installation of DG.33- and 69-bus systems at three different load levels vizLight, nominal, and heavy are used for testing the approached as well as other methods.The result was that the approached method was more effective in reducing power loss and improving the voltage profile as compared to other methods. Then this was studied at different load levels. The results showed that the percentage power loss reduction was improving as the number of DG installation locations were increasing from one to four, but rate of improvement

decreased when locations were increasing from one to four at all load levels. However, when the number of DG installation locations were three the ratio of percentage loss reduction to DG size was the highest. The HSA results were compared with the results of genetic algorithm (GA) and refined genetic algorithm (RGA). Final result was that the HSA performance was better than GA and RGA.

Savier and Das (2007) In this paper, the consumer loss connected to a radial system has been examined by the Quadratic-loss allocation scheme, which is based on branch current flow. Therefore, it is ensured each consumer has been allocated the losses only at branches for which current contributes to. A heuristic rule and fuzzy multiobjective algorithm in a radial distribution system is derived to solve the network reconfiguration problem. The analysis demonstrates that the network reconfiguration reduces system real-power loss and most consumers will pay less, due to reduction in the loss allocation. However, this may also result in an increase in the loss allocation to a small group of consumers. This can be addressed by modification of tariff structure. It is also observed that network reconfiguration would influence the real-power loss allocation to each consumer.

Zhang et al. (2022) The large-scale fast charging of EVs in the distribution network creates an issue of uneven temporal and spatial distribution of charging loads and voltage quality deterioration. This can be addressed by adjustable charging service fees for adjustable charging service fees. The charging guidance strategy will guide the users to charge reasonably, helping to reduce the charging cost and the distribution network's voltage quality is enhanced substantially. The spatial and temporal distribution is forecasted considering the grid constraints of urban traffic road network-distribution and fast charging loads of private cars based on trip chains and Monte Carlo methods is proposed. The load and voltage quality of the distribution network is taken into consideration and a flexible tiered charging service fee model is established. The trip time, charging service cost and power consumption are considered to construct a user charging location. The factors that are analysed for a weighted decision model are : voltage of distribution network nodes, user's charging pattern, the spatial and temporal distribution of regional charging loads. Other factors which are analysed include, revenue from charging station revenue & impact on user charging cost under the proposed strategy. The charging guidance strategy has impact on the distribution network, charging station operators and EV users, apart from changing the spatial and temporal distribution of fast charging loads/ The method results in the overall voltage deviation to 4.279 and significantly improves the voltage quality of the distribution network level. At user level, overall comprehensive charging cost is reduced to 9.28% motivating to respond and adapt the strategy. At charging station operators level, there has been a slight fall in their revenues & profit by the adoption of the charging guidance strategy. However, it is envisaged that in future the profit of charging station operators would go up due to the V2G technology development and the increasing use of EV. The approach of participation in grid interaction would be a futuristic research topic.

Simolin et al. (2022) This paper assesses the influence on EV charging load through the charging profile modelling method. Realistic sampling with four commercial EVs are experimented and compared. Also, REDI shopping centre's charging session data is used for a large charging site evaluation sample. It is found that, to avoid modelling errors, linear charging profile is not recommended for controlled charging. Measurement-based nonlinear charging profiles wage would lead to most accurate modelling However, usage of a simple, but justified, bilinear charging profile model is also recommended for a reasonably accurate result.

Based on the calculations, it is derived that in the constant voltage stage, the charging currents of commercial EVs decrease around 15.3 mA/s per phase on an average. It is further observed that if this value is used to model charging profiles, it will lead to a reasonable low modelling

error of 0.64%–4.39% for the highest hourly peak power and the charged energy. Therefore, it would help to study EV charging load modelling from the charging site point-of-view, enhancing its accuracy with reduced computational requirements. Also, the paper demonstrates that in the charging site, the battery temperatures do not have a substantial influence on the charging loads and therefore, may not be considered for further related studies. The paper also derives that uncontrolled charging can be modelled more accurately when compared to controlled charging. The different charging profile modelling accuracy for different control algorithms needs to be investigated further. However, this can be a challenging task because of the limitations on the currently available commercial EVs. For instance, few EVs may not support vehicle-to-grid or communicate information, such as SoC, to the control system. In addition, real time measurements are to be used as a baseline for the comparisons, otherwise different modelling methods cannot be assessed accurately.

# CHAPTER 3

## METHODOLOGY

### 3.1 Vehicle Classification

Electric vehicles have been classified primarily into four major categories as shown in Figure 3.1

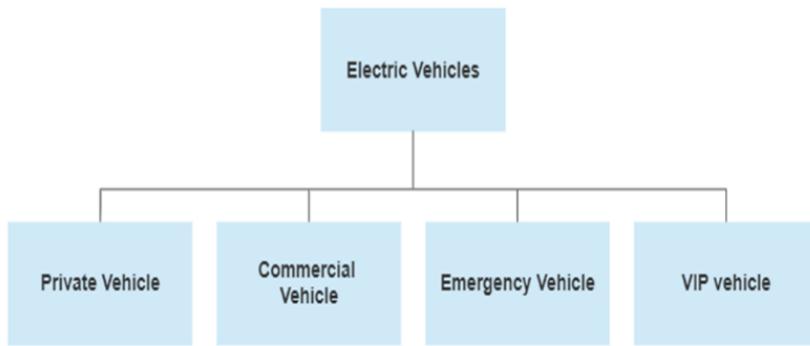


Figure 3.1: Vehicle Classification

The above classification is made by comparing the battery capacity of the vehicles from the data taken with the battery capacity of the similar kind of vehicles in the market.

Private vehicles are further classified into E-bikes and E-cars with average battery capacity of  $400\text{ Wh}$  to  $500\text{ Wh}$  and  $40\text{ kWh}$  to  $100\text{ kWh}$  respectively. Commercial vehicles are classified into E-Truck and E-Bus with an average battery capacity of  $100\text{ kWh}$  and  $60$  to  $548\text{ kWh}$  respectively. Emergency vehicles have a battery capacity of around  $105\text{ kWh}$  and VIP vehicles have around  $90\text{ kWh}$  to  $200\text{ kWh}$ .

### 3.2 Travel Pattern Establishment

Travel pattern for three main vehicle subcategories of the above mentioned vehicle categories namely E-car, E-Truck and E-Bus are now taken and travel patterns of the same have been established by using the Battery capacity, Time taken to full charge, Time period of the vehicle when it is connected to the grid , charging rate and discharging rate Lee et al. (2019).

Bus: ID – 16034 This id is chosen as the battery capacity of the bus is considered to be the best in market. The battery capacity range of bus is  $199.95\text{ KWH}$ . The time taken for  $100\%$  charging of battery happens to be 5 hours 20 minutes. It can run for 24 hours after full charging. The charging of bus would take place every alternative day as the bus takes 24 hours to complete its trip. The bus would have energy of  $12.5\text{ KWH}$  on completion of 20 minutes of charging when plugged at  $0\%$  Soc. It would have a time period of 5 hours 40 minutes to keep the vehicle idle or to discharge.

Car: ID – 13646 Car ID 13646 is chosen as it is the best in market for all the EV cars in recent times. The battery capacity range of car is 54 KWH. The time taken for full charge when plugged at 0% SoC is 1 hour 40 minutes. It can run for 6 hours 30 minutes after full charge. As the vehicle is a car its trip for a day can be 2 times and so the above pattern can be repeated for the second part of the day. Charge of the vehicle after 20 minutes of charging when plugged at 0% SoC is 10.8 KWH. After the completion of full charge it will have 3 hours 40 minutes for idle/ discharge period.

Truck: ID – 4428 Truck ID 4428 is considered as it is successful in market when compared with other trucks. The battery capacity range of bus is 99.2 KWH. It requires complete 4 hours to have 100% battery charge or 100% Soc. It takes 14 hours to fully utilize 99.2 KWH after full charge of the battery. As it takes 14 hours to complete its trip it is restricted for one day travel. The charge at the end of 20 minutes is 8.267 KWH. After the charging for 4 full hours it will have 6 hours for the vehicle to discharge or keep the vehicle idle.

### **3.3 Charging/Discharging pattern Establishment**

Generally for the travel pattern to be established, the time scale will be taken for 24 hours counting every hour. Here the time scale is considered to be 72 blocks as 1 hour is split into three 20 minute block for 24 hours because the classified vehicles have different battery capacity range. This split up is done to find the best efficient charging/discharging pattern in order to reduce the cost that is paid to the grid for the benefit of consumers.

### **3.4 Flowchart**

1. With the help of the device data calculate the time period T for which the vehicle is connected to the grid.
2. Calculate SoC threshold, $t$  for every vehicle.
3. The SoC residual, $t$  and SoC consumed, $t$  are determined for the time block  $t$ .  
The SoC residual, $t$  is compared with SoC threshold, $t$ 
  - If the condition is true then the time must be equal peak demand. If it is equal then the vehicle stays idle. If the time is not equal to peak demand then it is then checked with the real price algorithm and if it satisfies the algorithm then the vehicle goes to charging, if not the vehicle stays idle.
  - If the condition is not true then time is checked with the peak demand and the vehicle is given a priority of either 1 or 0. 1 means the vehicle has to charge and if 0 then the vehicle discharges when the time is equal to peak demand. When  $t$  and peak demand are not equal the vehicle stays idle.

### **3.5 Real Time Price**

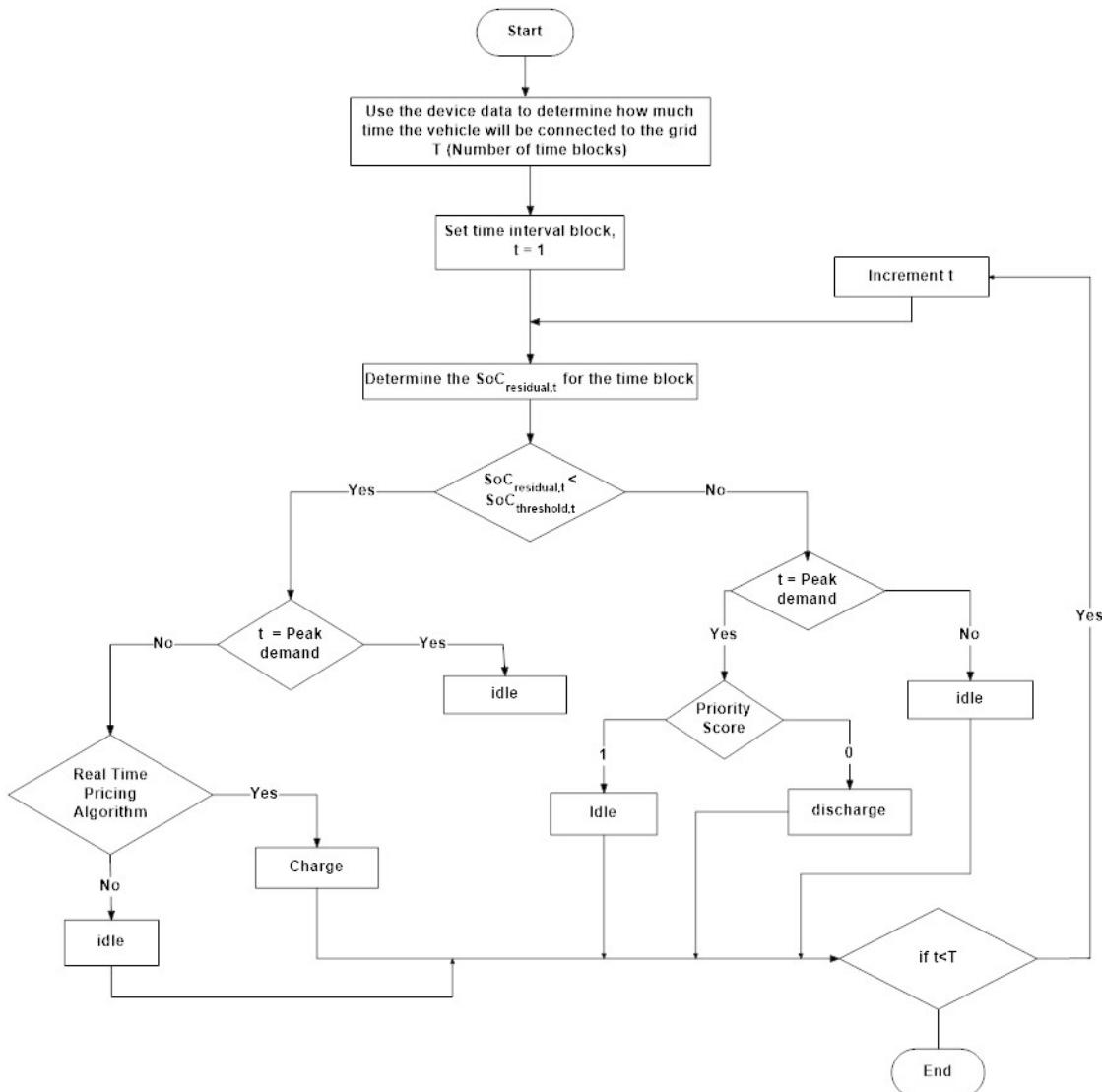


Figure 3.2

Hour	Price (\$/kWh)	Hour	Price (\$/kWh)	Hour	Price (\$/kWh)
1	0.033	9	0.215	17	0.086
2	0.027	10	0.572	18	0.059
3	0.020	11	0.572	19	0.050
4	0.017	12	0.572	20	0.061
5	0.017	13	0.215	21	0.181
6	0.029	14	0.572	22	0.077
7	0.033	15	0.286	23	0.043
8	0.054	16	0.279	24	0.037

Figure 3.3

# CHAPTER 4

## Mathematical Modelling

### 4.1 SoC Calculation

The SoC of the vehicle is calculated from the following equations:

$$SoC_{min} \leq SoC \leq SoC_{max} \quad (4.1)$$

where ‘ $SoC_{min}$ ’ and ‘ $SoC_{max}$ ’ are the minimum and maximum values of SoC and the values are 20 percent and 80 percent of SoC.

$$SoC_y = SoC_{y-1} + P_{batt}(y) \times \partial y \times \eta_c \quad (4.2)$$

Where ‘ $SoC_y$ ’ is the state of charge in present hour and ‘ $SoC_{y-1}$ ’ is the state of charge in the previous hour. ‘ $P_{battery}(y)$ ’ represents the power of the battery in the present hour. ‘ $\partial y$ ’ is the time interval and ‘ $\eta_c$ ’ is the charging efficiency which is considered to be 100 percent.

$$SoC_y = SoC_{y-1} - P_{batt}(y) \times \partial y \times \eta_d \quad (4.3)$$

Where ‘ $SoC_y$ ’ is the state of charge in present hour and ‘ $SoC_{y-1}$ ’ is the state of charge in the previous hour. ‘ $P_{battery}(y)$ ’ represents the power of the battery in the present hour. ‘ $\partial y$ ’ is the time interval and ‘ $\eta_d$ ’ is the discharging efficiency which is considered to be 100 percent.

$$P_{batt}(y) = SoC_y \times E \quad (4.4)$$

$P_{battery}(y)$ ’ represents the output power of the battery in the present hour, ‘ $SoC_y$ ’ is the state of charge in present hour and  $E$  is the energy of the battery.

$$InitialPower = Generation - Load \quad (4.5)$$

SoC limits:

$SoC_{min}$  and  $SoC_{max}$  are the maximum and minimum SoC of the EV respectively. This constraint allows the SoC to vary between predefined minimum and maximum SoC.

### 4.2 Best Pattern for charging

The charging pattern is determined by comparing the Energy required to the Real Time Price and by identifying the minimum of it.

$$T_n = \sum_{t=1}^{24} [Ch_t \times [1||0|| - 1]] * Rtp_i \quad (4.6)$$

where ' $T_n$ ' is the cost of ' $n^{th}$ ' iteration, ' $i$ ' ranges from 1 to 24, ' $Ch_t$ ' is the energy delivered at time ' $t$ ' and ' $Rtp_i$ ' is the real time price at the ' $i^{th}$ ' iteration. ' $[1||0|| - 1]$ ' represents the priority score for charging the vehicles.

The function ' $argmin$ ' is used to find the minimum cost from all the ' $n$ ' iterations.

### 4.3 Maximum Power required by EV

Maximum Power demand occurs when all the three vehicles loads are high and the time block of maximum demand is identified.

$$P_{t(total)} = P_{t(car)} + P_{t(truck)} + P_{t(bus)} \quad (4.7)$$

where ' $P_{t(car)}$ ', ' $P_{t(truck)}$ ', ' $P_{t(bus)}$ ' are the total power of car , truck and bus in  $kW$  respectively. ' $P_{t(total)}$ ' is the addition of the total power of the individual vehicles (i.e.) car , truck and bus.

$$P_{t(total)} = argmax \prod_{i=1}^{24} *P_{t(total)} \quad (4.8)$$

' $P_{t(total)}$ ' is the addition of the total power of the individual vehicles (i.e.) car , truck and bus. The function ' $argmax$ ' is used to find the value of power from the total power.

# CHAPTER 5

## RESULTS & DISCUSSION

### 5.1 Tabulations

Table 5.1: Power Loss when Ev connected in different busses in 33 bus system for two load profile scenarios

SCENARIO	Case 1 - (00:00)		Case 2 - (00:20)		Case 3 - (00:40)	
	Power Loss when Ev in Bus 2 (W)	Power Loss when Ev in Bus 18 (W)	Power Loss when Ev in Bus 2 (W)	Power Loss when Ev in Bus 18 (W)	Power Loss when Ev in Bus 2 (W)	Power Loss when Ev in Bus 18 (W)
<b>SCENARIO-1</b>	204.1038	253.746	65.7725	78.4603	204.1038	253.746
<b>SCENARIO-2</b>	189.8325	236.9117	178.9671	222.4681	189.8325	236.9117

VEHICLE TYPE	SCENARIO	BEST PRICE	HOUR
<b>CAR</b>	<b>Case 1 - (00:00)</b>	- \$1.71	12:00
	<b>Case 2 - (00:20)</b>	- \$2.09	01:20
	<b>Case 3 - (00:40)</b>	- \$1.58	01:40
<b>BUS</b>	<b>Case 1 - (00:00)</b>	- \$0.47	12:00
	<b>Case 2 - (00:20)</b>	- \$1.25	20:20
	<b>Case 3 - (00:40)</b>	- \$0.69	11:40
<b>TRUCK</b>	<b>Case 1 - (00:00)</b>	- \$2.57	05:00
	<b>Case 2 - (00:20)</b>	-\$1.00	04:20
	<b>Case 3 - (00:40)</b>	- \$2.11	04:40

Table 5.2: Hour at which the EV Load is maximum

SCENARIO	HOURLY	20MINS	40 MINS
SCENARIO 1	13 <sup>th</sup>	6 <sup>th</sup>	13 <sup>th</sup>
SCENARIO 2	19 <sup>th</sup>	6 <sup>th</sup>	19 <sup>th</sup>

### 5.2 Voltage Magnitude Graphs for Different Scenarios

### 5.3 \*\*\*\*\*

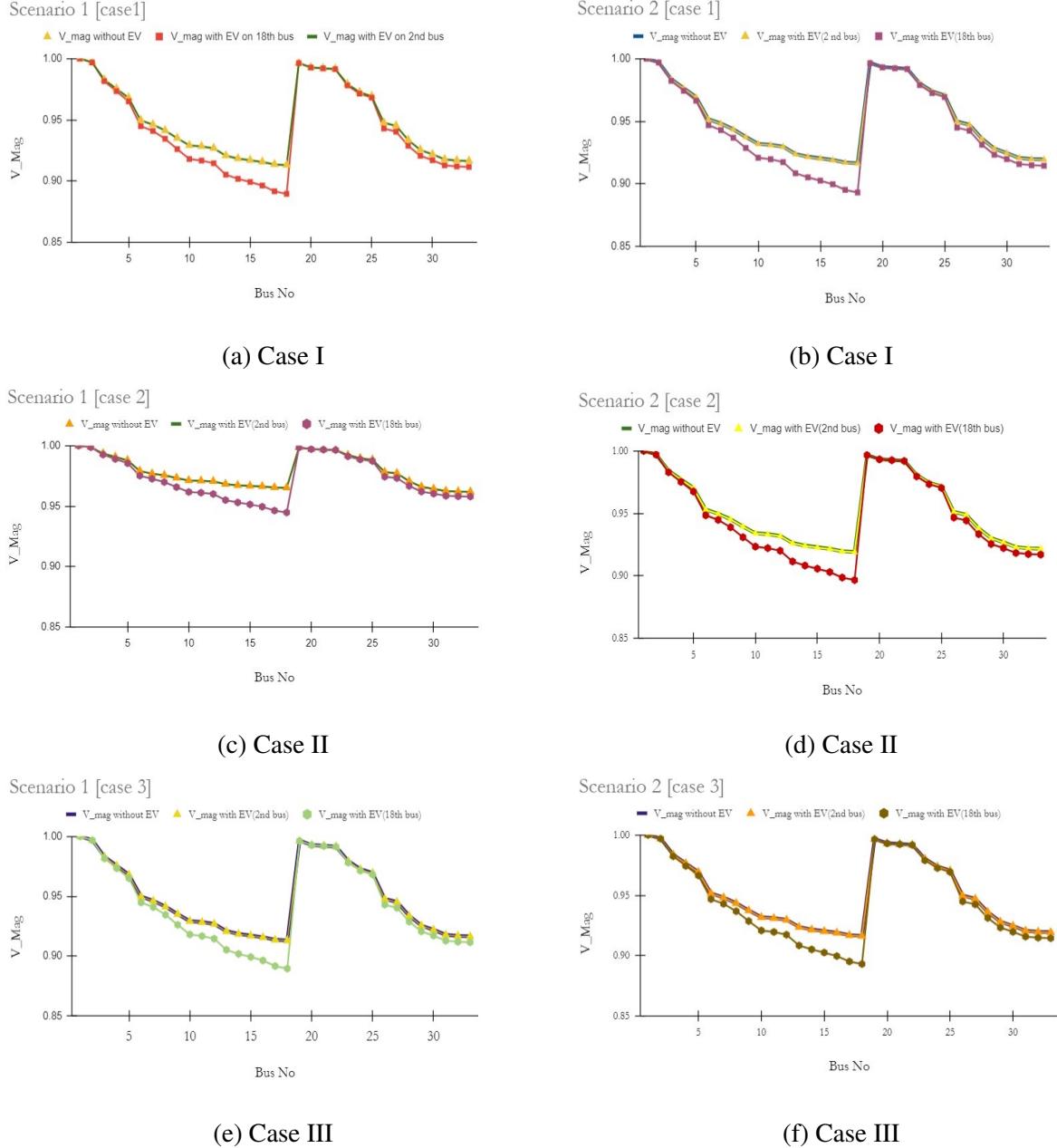


Figure 5.1: Voltage magnitude variation for different scenarios

## **CHAPTER 6**

### **CONCLUSIONS AND FURTHER WORK**

In the conclusion, you should restate the thesis and show how it has been developed through the body of the paper. Briefly summarize the key arguments made in the body, showing how each of them contributes to proving your thesis

**Signature of the Guide**

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**Name:**Mithra Vinda Reddy K

## **CONCLUSIONS**

In the conclusion, you should restate the thesis and show how it has been developed through the body of the paper. Briefly summarize the key arguments made in the body, showing how each of them contributes to proving your thesis

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## **CONCLUSIONS**

In the conclusion, you should restate the thesis and show how it has been developed through the body of the paper. Briefly summarize the key arguments made in the body, showing how each of them contributes to proving your thesis

**Signature of the Guide**

**Student Reg. No:**123005140

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## APPENDIX A

### IEEE 33 BUS SYSTEM

This test system and its data are referred from Rao et al. (2012). In base case (i.e) topology I, there are five open tie switches and branch numbers are 33, 34, 35, 36, and 37 respectively. In topology II, the five open tie switches and branch numbers are 7, 9, 14, 32, and 37 respectively. The single line diagram of the IEEE 33 bus system is shown in Fig. A.1. The total real and reactive power loads on the system are  $3715 \text{ kW}$  and  $2300 \text{ kVAr}$  respectively. The voltage magnitude of the system is  $1\angle 0^\circ \text{ p.u.}$

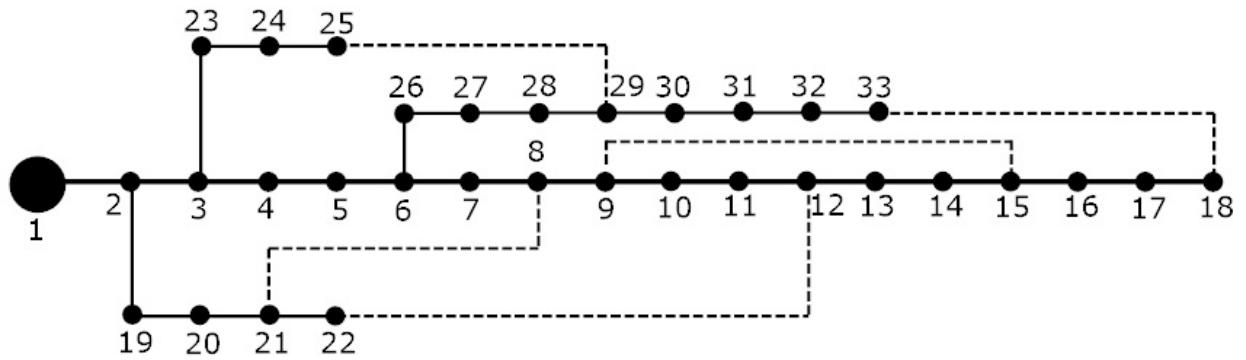


Figure A.1: Single line diagram of IEEE-33 Bus System

Table A.1: IEEE 33 Bus System Bus Data

Bus No.	Bus Code	Load Type	Load		Generator				Injected MVAr
			MW	MVAr	MW	MVAr	Qmin	Qmax	
1	1	-	0	0	0	0	0	0	0
2	0	Curtailable	0.100	0.060	0	0	0	0	0
3	0	Curtailable	0.090	0.040	0	0	0	0	0
4	0	Curtailable	0.120	0.080	0	0	0	0	0
5	0	Curtailable	0.060	0.030	0	0	0	0	0
6	0	Fixed	0.060	0.020	0	0	0	0	0
7	0	Fixed	0.200	0.100	0	0	0	0	0
8	0	Fixed	0.200	0.100	0	0	0	0	0
9	0	Fixed	0.060	0.020	0	0	0	0	0
10	0	Fixed	0.060	0.020	0	0	0	0	0
11	0	Fixed	0.045	0.020	0	0	0	0	0
12	0	Controllable	0.060	0.035	0	0	0	0	0
13	0	Controllable	0.060	0.035	0	0	0	0	0
14	0	Controllable	0.120	0.080	0	0	0	0	0
15	0	Controllable	0.060	0.010	0	0	0	0	0
16	0	Controllable	0.060	0.020	0	0	0	0	0
17	0	Controllable	0.060	0.020	0	0	0	0	0
18	0	Controllable	0.090	0.040	0	0	0	0	0
19	0	Controllable	0.090	0.040	0	0	0	0	0
20	0	Controllable	0.090	0.040	0	0	0	0	0
21	0	Controllable	0.090	0.040	0	0	0	0	0
22	0	Controllable	0.090	0.040	0	0	0	0	0
23	0	Controllable	0.090	0.050	0	0	0	0	0
24	0	Controllable	0.420	0.200	0	0	0	0	0
25	0	Controllable	0.420	0.200	0	0	0	0	0
26	0	Curtailable	0.060	0.025	0	0	0	0	0
27	0	Curtailable	0.060	0.025	0	0	0	0	0
28	0	Curtailable	0.060	0.020	0	0	0	0	0
29	0	Curtailable	0.120	0.070	0	0	0	0	0
30	0	Curtailable	0.200	0.600	0	0	0	0	0
31	0	Curtailable	0.150	0.070	0	0	0	0	0
32	0	Curtailable	0.210	0.100	0	0	0	0	0
33	0	Curtailable	0.060	0.040	0	0	0	0	0

Bus Code

1 - Slack Bus

0 - Load Bus

Table A.2: IEEE 33 Bus System Line Data

Line No.	From Bus	To Bus	R (p.u)	X (p.u)	B (p.u)	line code = 1 for lines > 1 or <1 for tr.tap	Failure Rate (f/yr)	Repair Time (h)
1	1	2	0.0922	0.0470	0	1	0.05	1.0
2	2	3	0.4930	0.2511	0	1	0.30	1.0
3	3	4	0.3660	0.1864	0	1	0.22	1.0
4	4	5	0.3811	0.1941	0	1	0.23	1.0
5	5	6	0.8190	0.7070	0	1	0.51	1.0
6	6	7	0.1872	0.6188	0	1	0.11	1.0
7	7	8	0.7115	0.2351	0	1	0.44	1.0
8	8	9	1.0300	0.7400	0	1	0.64	1.0
9	9	10	1.0440	0.7400	0	1	0.65	1.0
10	10	11	0.1967	0.0651	0	1	0.12	1.0
11	11	12	0.3744	0.1238	0	1	0.23	1.0
12	12	13	1.4680	1.1550	0	1	0.91	1.0
13	13	14	0.5416	0.7129	0	1	0.33	1.0
14	14	15	0.5909	0.5260	0	1	0.36	1.0
15	15	16	0.7463	0.5450	0	1	0.46	1.0
16	16	17	1.2890	1.7210	0	1	0.80	1.0
17	17	18	0.7320	0.5740	0	1	0.45	1.0
18	2	19	0.1640	0.1565	0	1	0.10	0.5
19	19	20	1.5042	1.3554	0	1	0.93	0.5
20	20	21	0.4095	0.4784	0	1	0.25	0.5
21	21	22	0.7089	0.9373	0	1	0.44	0.5
22	3	23	0.4512	0.3083	0	1	0.28	0.5
23	23	24	0.8990	0.7011	0	1	0.56	0.5
24	24	25	0.8960	0.7011	0	1	0.55	0.5
25	6	26	0.2030	0.1034	0	1	0.12	0.5
26	26	27	0.2842	0.1447	0	1	0.17	0.5
27	27	28	1.0590	0.9337	0	1	0.66	0.5
28	28	29	0.8043	0.7006	0	1	0.50	0.5
29	29	30	0.5075	0.2585	0	1	0.31	0.5
30	30	31	0.9744	0.9630	0	1	0.60	0.5
31	31	32	0.3105	0.3619	0	1	0.19	0.5
32	32	33	0.6411	0.5302	0	1	0.21	0.5
33*	8	21	2.0000	2.0000	0	1	1.24	0.5
34*	9	15	2.0000	2.0000	0	1	1.24	0.5
35*	12	22	2.0000	2.0000	0	1	1.24	0.5
36*	18	33	0.5000	0.5000	0	1	0.31	0.5
37*	25	29	0.5000	0.5000	0	1	0.31	0.5

\*- Tie Line

## APPENDIX B

### IEEE 69 BUS SYSTEM

This test system and its data are referred from Savier and Das (2007). In base case (i.e) topology I, there are five open tie switches and branch numbers are 68, 69, 70, 71, and 72 respectively. In topology II, the five open tie switches and branch numbers are 13, 18, 56, 61, and 69 respectively. The single line diagram of the IEEE 69 bus system is shown in Fig. B.1. The total real and reactive power loads on the system are  $3802.19 \text{ kW}$  and  $2694.06 \text{ kVAr}$  respectively. The voltage magnitude of the system is  $1\angle 0^\circ \text{ p.u.}$

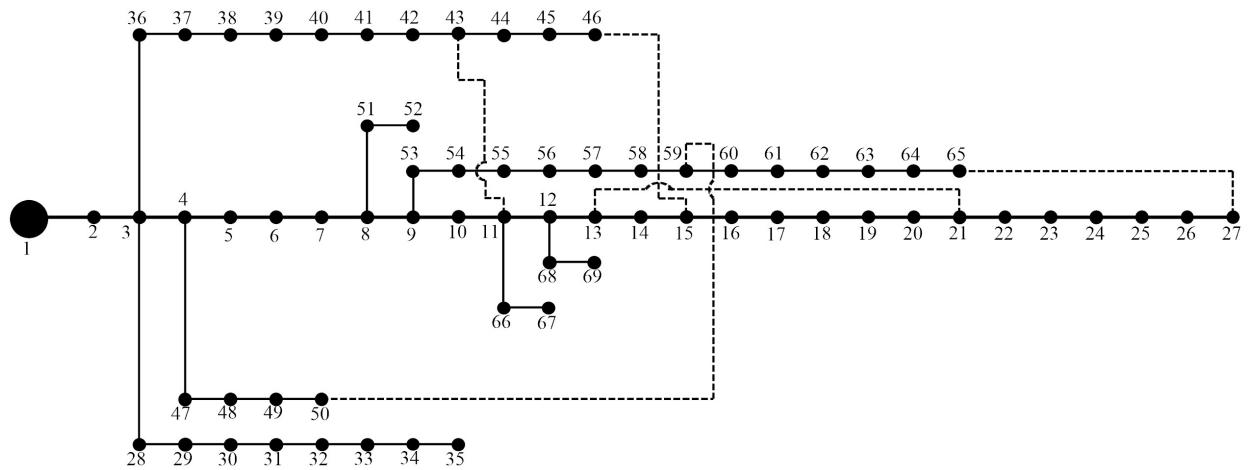


Figure B.1: Single line diagram of IEEE-69 Bus System

Table B.1: IEEE 69 Bus System Bus Data

Bus No.	Bus Code	Load Type	Load		Generator				Injected MVAr
			MW	MVAr	MW	MVAr	Qmin	Qmax	
1	1	-	0	0	0	0	0	0	0
2	0	Curtailable	0	0	0	0	0	0	0
3	0	Curtailable	0	0	0	0	0	0	0
4	0	Curtailable	0	0	0	0	0	0	0
5	0	Curtailable	0	0	0	0	0	0	0
6	0	Fixed	0.0026	0.0022	0	0	0	0	0
7	0	Controllable	0.0404	0.0030	0	0	0	0	0
8	0	Fixed	0.0750	0.0054	0	0	0	0	0
9	0	Fixed	0.0300	0.0022	0	0	0	0	0
10	0	Fixed	0.0280	0.0019	0	0	0	0	0
11	0	Fixed	0.1450	0.1040	0	0	0	0	0
12	0	Fixed	0.1450	0.1040	0	0	0	0	0
13	0	Controllable	0.0080	0.0055	0	0	0	0	0
14	0	Controllable	0.0080	0.0055	0	0	0	0	0
15	0	Controllable	0	0	0	0	0	0	0
16	0	Controllable	0.0455	0.0030	0	0	0	0	0
17	0	Controllable	0.0600	0.0350	0	0	0	0	0
18	0	Controllable	0.0600	0.0350	0	0	0	0	0
19	0	Controllable	0	0	0	0	0	0	0
20	0	Controllable	0.0010	0.0006	0	0	0	0	0
21	0	Controllable	0.1140	0.0810	0	0	0	0	0
22	0	Controllable	0.0530	0.0035	0	0	0	0	0
23	0	Controllable	0	0	0	0	0	0	0
24	0	Controllable	0.0280	0.020	0	0	0	0	0
25	0	Controllable	0	0	0	0	0	0	0
26	0	Controllable	0.0140	0.0100	0	0	0	0	0
27	0	Curtailable	0.0140	0.0100	0	0	0	0	0
28	0	Curtailable	0.0260	0.0186	0	0	0	0	0
29	0	Curtailable	0.0260	0.0186	0	0	0	0	0
30	0	Curtailable	0	0	0	0	0	0	0
31	0	Curtailable	0	0	0	0	0	0	0
32	0	Curtailable	0	0	0	0	0	0	0
33	0	Curtailable	0.0140	0.0100	0	0	0	0	0
34	0	Curtailable	0.0195	0.0140	0	0	0	0	0
35	0	Controllable	0.0060	0.0040	0	0	0	0	0
36	0	Controllable	0.0260	0.01855	0	0	0	0	0
37	0	Controllable	0.026	0.01855	0	0	0	0	0
38	0	Controllable	0	0	0	0	0	0	0
39	0	Controllable	0.0240	0.0170	0	0	0	0	0
40	0	Controllable	0.0240	0.0170	0	0	0	0	0
41	0	Controllable	0.0012	0.0100	0	0	0	0	0
42	0	Controllable	0	0	0	0	0	0	0

43	0	Controllable	0.0060	0.0043	0	0	0	0	0
44	0	Controllable	0	0	0	0	0	0	0
45	0	Controllable	0.03922	0.05263	0	0	0	0	0
46	0	Controllable	0.03922	0.0263	0	0	0	0	0
47	0	Controllable	0	0	0	0	0	0	0
48	0	Controllable	0.0790	0.0564	0	0	0	0	0
49	0	Curtailable	0.3847	0.2745	0	0	0	0	0
50	0	Controllable	0.3847	0.2745	0	0	0	0	0
51	0	Curtailable	0.0405	0.0283	0	0	0	0	0
52	0	Curtailable	0.0036	0.0027	0	0	0	0	0
53	0	Curtailable	0.00435	0.0035	0	0	0	0	0
54	0	Curtailable	0.0264	0.0190	0	0	0	0	0
55	0	Curtailable	0.0240	0.0172	0	0	0	0	0
56	0	Curtailable	0	0	0	0	0	0	0
57	0	Fixed	0	0	0	0	0	0	0
58	0	Fixed	0	0	0	0	0	0	0
59	0	Fixed	0.1000	0.0720	0	0	0	0	0
60	0	Fixed	0	0	0	0	0	0	0
61	0	Controllable	1.2440	0.8880	0	0	0	0	0
62	0	Fixed	0.0320	0.0230	0	0	0	0	0
63	0	Fixed	0	0	0	0	0	0	0
64	0	Fixed	0.2270	0.1620	0	0	0	0	0
65	0	Fixed	0.0590	0.0420	0	0	0	0	0
66	0	Fixed	0.0180	0.0130	0	0	0	0	0
67	0	Fixed	0.0180	0.0130	0	0	0	0	0
68	0	Fixed	0.0280	0.0200	0	0	0	0	0
69	0	Controllable	0.02800	0.0200	0	0	0	0	0

#### Bus Code

1 - Slack Bus

0 - Load Bus

Table B.2: IEEE 69 Bus System Line Data

Line No.	From Bus	To Bus	R (p.u)	X (p.u)	B (p.u)	line code = 1 for lines > 1 or <1 for tr.tap	Failure Rate (f/yr)	Repair Time (h)
1	1	2	0.0005	0.0012	0	1	0.0003	0.5
2	2	3	0.0005	0.0012	0	1	0.0003	0.5
3	3	4	0.0015	0.0036	0	1	0.0009	0.5
4	4	5	0.0251	0.0294	0	1	0.0156	0.5
5	5	6	0.3660	0.1864	0	1	0.2269	0.5
6	6	7	0.3811	0.1941	0	1	0.2363	0.5

7	7	8	0.0922	0.0470	0	1	0.0572	0.5
8	8	9	0.0493	0.0251	0	1	0.0306	0.5
9	9	10	0.8190	0.2707	0	1	0.5078	0.5
10	10	11	0.1872	0.0619	0	1	0.1161	0.5
11	11	12	0.7114	0.2351	0	1	0.4411	0.5
12	12	13	1.0300	0.3400	0	1	0.6386	0.5
13	13	14	1.0440	0.3450	0	1	0.6473	0.5
14	14	15	1.0580	0.3496	0	1	0.6560	0.5
15	15	16	0.1966	0.0650	0	1	0.1219	0.5
16	16	17	0.3744	0.1238	0	1	0.2321	0.5
17	17	18	0.0047	0.0016	0	1	0.0029	0.5
18	18	19	0.3276	0.1083	0	1	0.2031	0.5
19	19	20	0.2106	0.0690	0	1	0.1306	0.5
20	20	21	0.3416	0.1129	0	1	0.2118	0.5
21	21	22	0.0140	0.0046	0	1	0.0087	0.5
22	22	23	0.1591	0.0526	0	1	0.0986	0.5
23	23	24	0.3463	0.1145	0	1	0.2147	0.5
24	24	25	0.7488	0.2745	0	1	0.4643	0.5
25	25	26	0.3089	0.1021	0	1	0.1915	0.5
26	26	27	0.1732	0.0572	0	1	0.1074	0.5
27	3	28	0.0044	0.0108	0	1	0.0027	1.0
28	28	29	0.0640	0.1565	0	1	0.0397	1.0
29	29	30	0.3978	0.1315	0	1	0.2466	1.0
30	30	31	0.0702	0.0232	0	1	0.0435	1.0
31	31	32	0.3510	0.1160	0	1	0.2176	1.0
32	32	33	0.8390	0.2816	0	1	0.5202	1.0
33	33	34	1.7080	0.5646	0	1	1.0590	1.0
34	34	35	1.4740	0.4873	0	1	0.9139	1.0
35	3	36	0.0044	0.0108	0	1	0.0270	1.0
36	36	37	0.0640	0.1565	0	1	0.0397	1.0
37	37	38	0.1053	0.1230	0	1	0.0653	1.0
38	38	39	0.0304	0.0355	0	1	0.0188	1.0
39	39	40	0.0018	0.0021	0	1	0.0011	1.0
40	40	41	0.7283	0.8509	0	1	0.4515	1.0
41	41	42	0.3100	0.3623	0	1	0.1922	1.0
42	42	43	0.0410	0.0478	0	1	0.0254	1.0
43	43	44	0.0092	0.0116	0	1	0.0057	1.0
44	44	45	0.1089	0.1373	0	1	0.0675	1.0
45	45	46	0.0009	0.0012	0	1	0.0006	1.0
46	4	47	0.0034	0.0084	0	1	0.0021	1.0
47	47	48	0.0851	0.2083	0	1	0.0528	1.0
48	48	49	0.2898	0.7091	0	1	0.1797	1.0
49	49	50	0.0822	0.2011	0	1	0.5100	1.0
50	8	51	0.0928	0.0473	0	1	0.0575	1.0
51	51	52	0.3319	0.1114	0	1	0.2058	1.0
52	9	53	0.1740	0.0886	0	1	0.1079	1.0

53	53	54	0.2030	0.1034	0	1	0.1259	1.0
54	54	55	0.2842	0.1447	0	1	0.1762	1.0
55	55	56	0.2813	0.1433	0	1	0.1744	1.0
56	56	57	1.5900	0.5337	0	1	0.9858	1.0
57	57	58	0.7837	0.263	0	1	0.4859	1.0
58	58	59	0.3042	0.1006	0	1	0.1886	1.0
59	59	60	0.3861	0.1172	0	1	0.2394	1.0
60	60	61	0.5075	0.2585	0	1	0.3146	1.0
61	61	62	0.0974	0.0496	0	1	0.6040	1.0
62	62	63	0.1450	0.0738	0	1	0.0899	1.0
63	63	64	0.7105	0.3619	0	1	0.4405	1.0
64	64	65	1.0410	0.5302	0	1	0.6454	1.0
65	11	66	0.2012	0.0611	0	1	0.1247	1.0
66	66	67	0.0047	0.0014	0	1	0.0029	1.0
67	12	68	0.7394	0.2444	0	1	0.4584	1.0
68	68	69	0.0047	0.0016	0	1	0.0029	1.0
69*	11	43	0.5000	0.5000	0	1	0.3100	1.0
70*	13	21	0.5000	0.5000	0	1	0.3100	1.0
71*	15	46	1.0000	1.0000	0	1	0.6200	1.0
72*	50	59	2.0000	2.0000	0	1	1.2100	1.0
73*	27	65	1.0000	1.0000	0	1	0.6200	1.0

\*- Tie Line