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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December 2022

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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.

Signature of Project Supervisor:

Name with Affliation : **Dr. Narayanan K (SAP / EEE / SEEE)**

Date : 06 / 12 / 2022

Project *Vivavoce* held on

Examiner-I **Examiner-II**

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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.

Signature of the candidate(s) :

Name of the candidate(s)	**: Mithra Vinda Reddy K**
	: Sarvesh Babu R G
	: Shwetha S
Date	: 06 / 12 / 2022

ACKNOWLEDGEMENTS

We express our gratitude to honourable **Dr. S. Vaidhyasubramaniam**, Vice Chancellor SASTRA University forcm the opportunity of pursuing our engineering in this esteemed in institution and carry out the project work.

We thank **Dr. R. Chandramouli**, Registrar, SASTRA University for granting permission and extending the facilities in carrying out this project.

We express our sincere thanks and gratitude to **Dr. K. Thenmozhi**, Dean, SEEE and **Dr. K. Vijayarekha**, Associate Dean, EEED/SEEE SASTRA Deemed to be University, for her support in the supporting the accomplishment of this work.

We also render our sincere thanks to project coordinators, **Dr. Karthikaikannan D**, SAP/EEE/SEEE and **Dr. Venkatesh T**, AP-III/EEE/SEEE, SASTRA Deemed to be University for their involvement and encouragement during this project.

We would like to thank our guide, **Dr. Narayanan K**, SAP/EEE/SEEE, SASTRA Deemed to be University, for his guidance and support, that cumulated to his successful project. His emphasis on making learning an experience allowed us to learn while making mistakes and rectifying them to learn ,not only the scientific concepts behind power systems but also the process of analysing results.

We would like to thank our friends who supported us. We would also like to thank the lab assistants for helping us with their practical expertise and for providing the necessary software tools.

And finally, we would like to acknowledge the appreciation and support that our parents provided to ensure we faced minimal obstacles throughout the project.

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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Name of the Guide: Dr. Narayanan K (SAP/EEE/SEEE) **Name:**Mithra Vinda Reddy K

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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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

- 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

EV	Electric Vehicle
RTP	Real Time Price

NOTATIONS

$SoC_{(y)}$	State of Charge in present hour
$SoC_{(y-1)}$	State of Charge in previous hour
ηc	Charging Efficiency
ηd	Discharging Efficiency
∂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.

Pollution, demand for fuel, global warming are the major problems in our livelihood and EVs are eco-friendly means of transport. This is why EVs are been promoted or has been brought into the market in recent times.

These vehicles may be powered through the charging docs or a collector system from off-vehicle sources or may have in-built battery system, solar panel, fuel cell or electric generator to convert fuel to electricity to drive the vehicle. 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.

Many factors have made EVs an urgent need in the present. Electric vehicles have the potential to reshape the transportation sector, drastically cutting carbon emissions and clearing the way for significant climate progress. EV s help to conserve non-renewable natural resources. Due 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 gases, 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.

One of the method is battery storage. To know about the battery storage, the vehicle's battery capacity must be known. Here concentrating on vehicle's battery capacity it can range from below hundred KWH to above hundred kWh for different vehicles.

But in present times there are difficulties based on how to charge EV s 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 differ 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 EV s are the new means of transport to fulfil the larger demand of people growing day by day.

The remainder of the thesis is organized as follows:

- A literature review 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 solar PV, wind-based renewable DG, and EV are presented in chapter 4.

- The chapter 5 results obtained for the considered test systems 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

The objectives of this project are:

- xyz
- 123
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CHAPTER 3

METHODOLOGY

3.1 Vehicle Classification

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

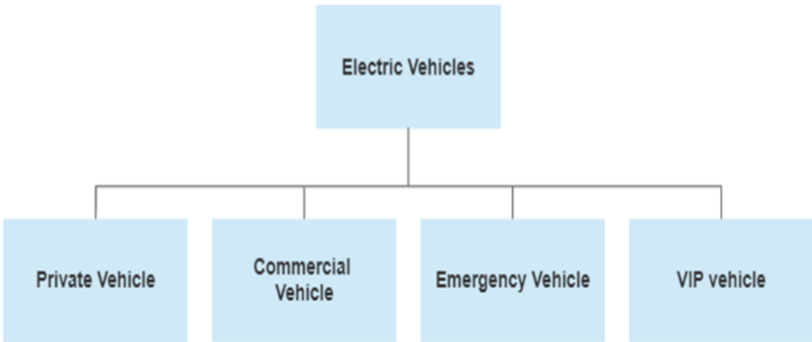

Figure 3.1: Vehicle Classification

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 Wh to 500 Wh and 40 kWh to 100 kWh respectively. Commercial vehicles are classified into E-Truck and E-Bus with an average battery capacity of 100 kWh and 60 to 548 kWh respectively. Emergency vehicles have a battery capacity of around 105 kWh and VIP vehicles have around 90 kWh to 200 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).

3.3 Charging/Discharging pattern Establishment

CHAPTER 4

Mathematical Modelling

4.1 SoC Calculation

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

$$SoC_{min} \leq SoC \leq SoC_{max} \tag{4.1}$$

$$SoC_y = SoC_{y-1} + P_{batt}(y) \times \partial y \times \eta c \tag{4.2}$$

$$SoC_y = SoC_{y-1} - P_{batt}(y) \times \partial y \times \eta d \tag{4.3}$$

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

$$InitialPower = Generation - Load \tag{4.5}$$

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.

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

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.

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

$$P_{t(total)} = \text{argmax}\ \pi_i^{24} * P_{t(total)}$$

4.4 Equation References - Siva

$$Z = \sum_{t=1}^{24} [P_{Fix}(t) * C(t) + \alpha * P_{Curt}(t) * C(t) + \beta * P_{Contr}(t) * C(t)] - [RTP(t) * P_G(t) + P_{RE}(t)] \tag{4.6}$$

where, 'Z' is the profit of the utility, '$P_{Fix}(t)$' , '$P_{Curt}(t)$' and '$P_{Contr}(t)$' are the fixed, curtailable and controllable power demand at the time duration 't' in kW. 'P_G' and 'P_{RE}' is the total power from grid and power generated by renewables at time 't' in kW, '$C(t)$' is cost at that specific time interval in \$, RTP is real time price in \$ and 'α' and 'β' is potential of load curtailment and shifting at time 't' respectively. In this work, five different cases are investigated to analyze the impact of the proposed DR in improving the utility's profit.

When the power generated by renewable resources is used to supply the required total demand with the remaining power required being supplied from the grid. Then total power is,

$$P_{Total} = \sum_{t=1}^{24} [P_{RE}(t) + P_G(t)] \tag{4.7}$$

The condition of load shifting is not required if the total available load is supplied by the renewables. This is stated as,

$$P_{RE}(t) > P_G(t) \tag{4.8}$$

i.e. Maximum available power is greater than the required load.

$$P_{max}(t) \geq P_{load}(t) \tag{4.9}$$

where, '$P_{max}(t)$' is the maximum avaialable power at a particular time 't' in kW and '$P_{load}(t)$' is total power required by the grid in specific time interval 't' in kW. Whereas, the required energy is supplied by the renewables in assistance with grid can be termed as,

$$P_{RE}(t) < P_{load}(t) < P_{max}(t) \tag{4.10}$$

Meanwhile when the necessary demand is met by the renewables and supply from the grid along with load shiting can be expressed as,

$$P_{RE}(t) < P_{max}(t) < P_{load}(t) \tag{4.11}$$

$$P_s(i) = \frac{\sum_{k=1}^{i} fitness(k)}{\sum_{j=1}^{N} fitness(j)} \tag{4.12}$$

AENS is average energy not supplied index and is expressed in terms of kilowatt hour per customer.

$$AENS = \frac{Total\, energy\, not\, supplied}{Total\, number\, of\, customers\, served} \tag{4.13}$$

$$AENS = \frac{\sum L_{a(i)} U_i}{N_i} \tag{4.14}$$

$$A = \frac{1}{\left(V_{ci-in} - V_r\right)^2} \left\{ V_{ci-in} \left(V_{ci-in} + V_r\right) - 4V_{ci-in} V_r \left[\frac{V_{c-in} + V_r}{2V_r}\right]^3 \right\} \tag{4.15}$$

$$B = \frac{1}{\left(V_{c-in} - V_r\right)^2} \left\{ 4\left(V_{c-in} + V_r\right) \left[\frac{V_{c-in} + V_r}{2V_r}\right]^3 - \left(3V_{c-in} + V_r\right) \right\} \tag{4.16}$$

$$C = \left(\frac{1}{\left(V_{c-in} - V_r\right)^2}\right) \left\{ 2 - 4\left[\frac{V_{c-in} + V_r}{2V_r}\right]^3 \right\} \tag{4.17}$$

'P_r' is the wind turbine's rated power in kW, 'V_{c-in}' is wind turbine's cut-in speed in m/s, 'V_{c-out}' is wind turbine's cut-out speed in m/s and 'V_r' rated speed of wind turbine in m/s.

$$0 \leq P_w \leq P_w^{max} \tag{4.18}$$

Where 'P_w' is the wind power generated in kW and 'P_w^{max}' is the maximum available wind power in kW.

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)
SCENARIO-1	204.1038	253.746	65.7725	78.4603	204.1038	253.746
SCENARIO-2	189.8325	236.9117	178.9671	222.4681	189.8325	236.9117

Scenario	Best price	Hour
Case 1 - (00:00)	- $1.71	12:00
Case 2 - (00:20)	- $2.0988	01:20
Case 3 - (00:40)	- $1.584	01:40

Table 5.2: Best pricing for Car during various connection time

Scenario	Best price	Hour
Case 1 - (00:00)	- $2.579304	05:00
Case 2 - (00:20)	- $1.003062667	04:20
Case 3 - (00:40)	- $2.110840667	04:40

Table 5.3: Best pricing for Truck during various connection time

5.2 Voltage Magnitude Graphs for Different Scenarios

5.3 *****

Scenario	Best price	Hour
Case 1 - (00:00)	- $0.4791666667	12:00
Case 2 - (00:20)	- $1.25	20:20
Case 3 - (00:40)	- $0.6958333333	11:40

Table 5.4: Best pricing for Bus during various connection time

Table 5.5: Hour at which the EV Load is maximum

SCENARIO	HOURLY	20MINS	40 MINS
SCENARIO 1	13^{th}	6^{th}	13^{th}
SCENARIO 2	19^{th}	6^{th}	19^{th}

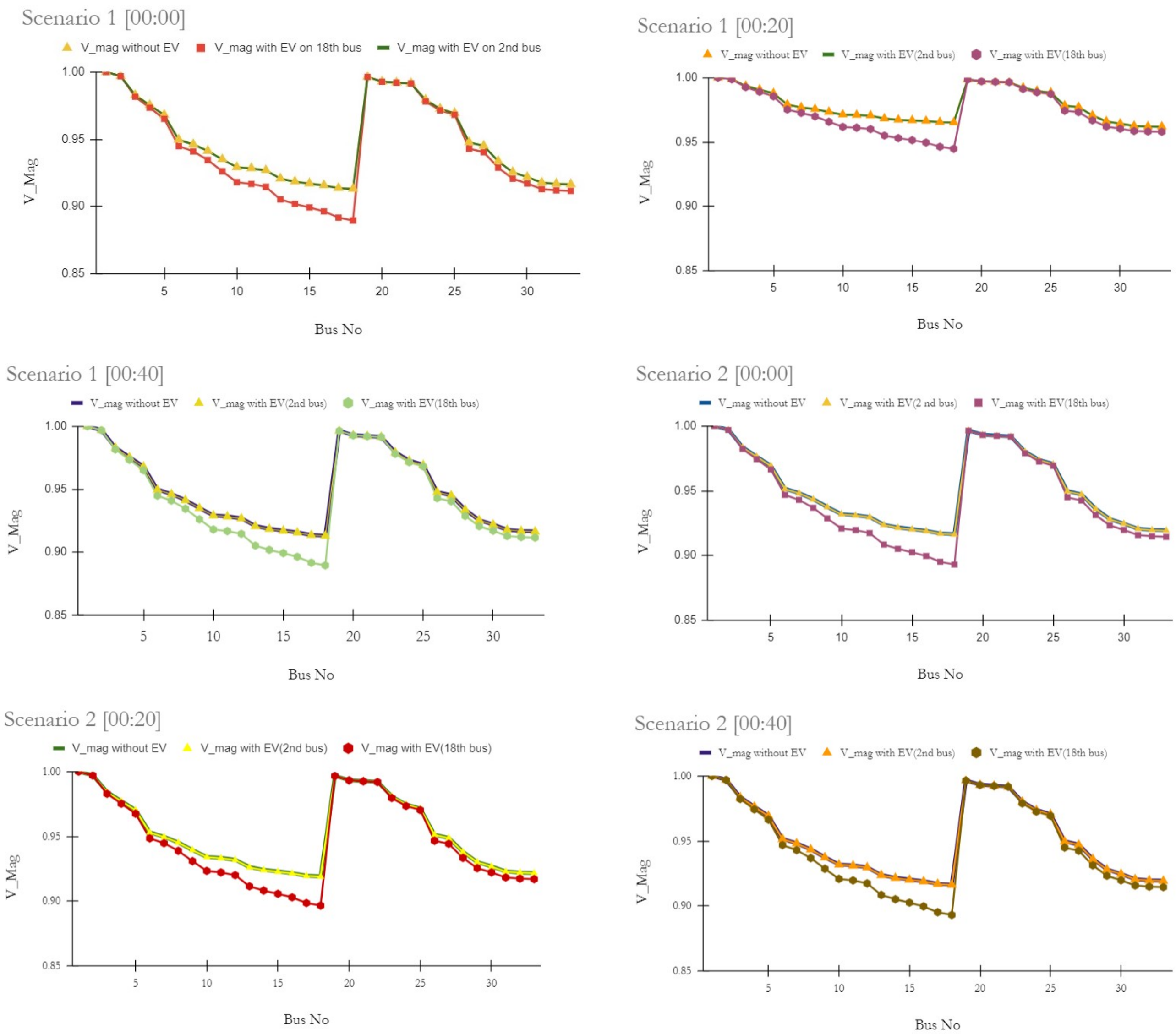

Figure 5.1: Voltage magnitude variation for different scenarios

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

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Name of the Guide: Dr. Narayanan K (SAP/EEE/SEEE) **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

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Rao, R. S., K. Ravindra, K. Satish, and S. Narasimham (2012). Power loss minimization in distribution system using network reconfiguration in the presence of distributed generation. *IEEE transactions on power systems 28*(1), 317–325.

Savier, J. and D. Das (2007). Impact of network reconfiguration on loss allocation of radial distribution systems. *IEEE Transactions on Power Delivery 22*(4), 2473–2480.

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 kW and 2300 $kVAr$ respectively. The voltage magnitude of the system is $1\angle 0°$ p.u.

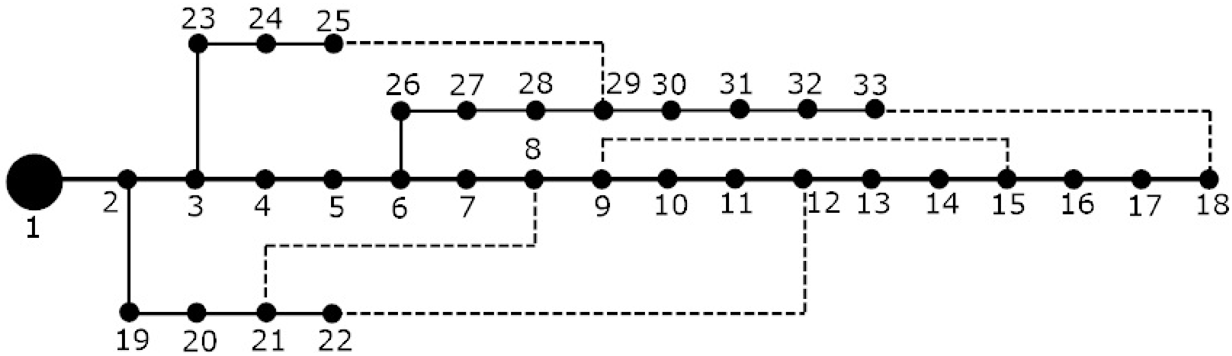

Figure A.1: Single line diagram of IEEE-33 Bus System

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 kW and 2694.06 $kVAr$ respectively. The voltage magnitude of the system is $1\angle 0°$ p.u.

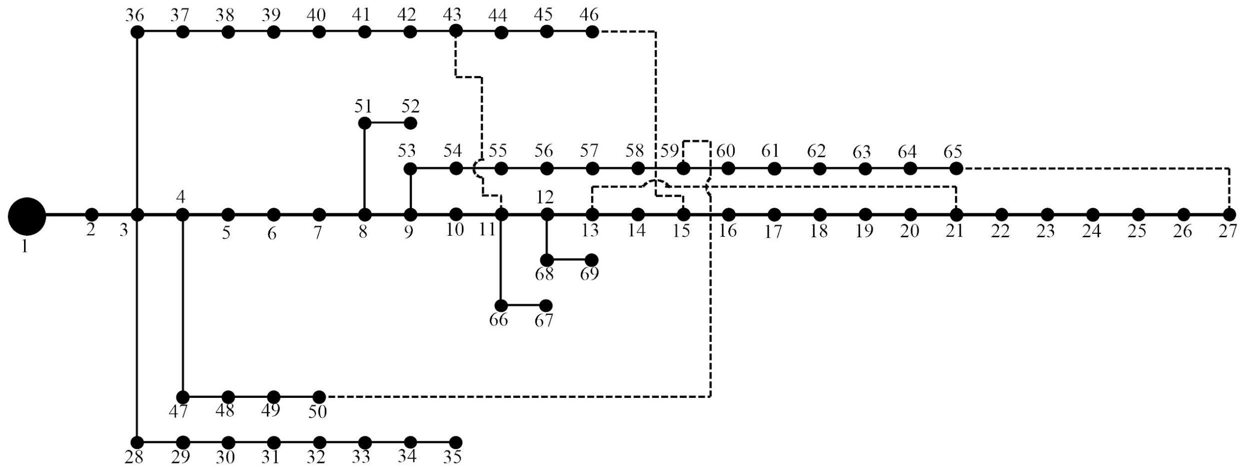

Figure B.1: Single line diagram of IEEE-69 Bus System

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