ISGF
India Smart Grid Forum

Electrical Safety Hazard Mitigation at Bus Depots for Electric Vehicle Supply Equipment (EVSE)

OCTOBER 2022

INDIA SMART GRID FORUM
CBIP Building, Malcha Marg, Chanakyapuri
New Delhi 110021

Authors and Acknowledgements

Authors

India Smart Grid Forum

Anand Singh

Balasubramanyam K

Bhushan Khade

Parul Shribatham

Ramachandran Pillai

Reena Suri

Reji Kumar Pillai

Acknowledgments

We would like to thank Mr. Om Prakash Bakoria, CMD and Mr. Prashant Kolekar, Electrical Engineer, Pune Mahanagar Parivahan Mahamandal Limited (PMPML) for providing the necessary support required for this study in Pune.

We would like to thank Mr. Sachin Talewar, Chief Engineer – Pune Urban, Maharashtra State Electricity Distribution Company Ltd (MSEDCL) and the MSEDCL team for providing all the necessary support required for the study in Pune.

We would like to thank Mr. Rajanvir Singh Kapur, Managing Director, WBTC and the WBTC team for providing all the necessary support required for this study in Kolkata.

We would like to thank Mr. Ravi Seethapathy, Advisor, ISGF and Executive Chairman, Biosirus Inc., Canada for providing necessary guidance and support to undertake the study.

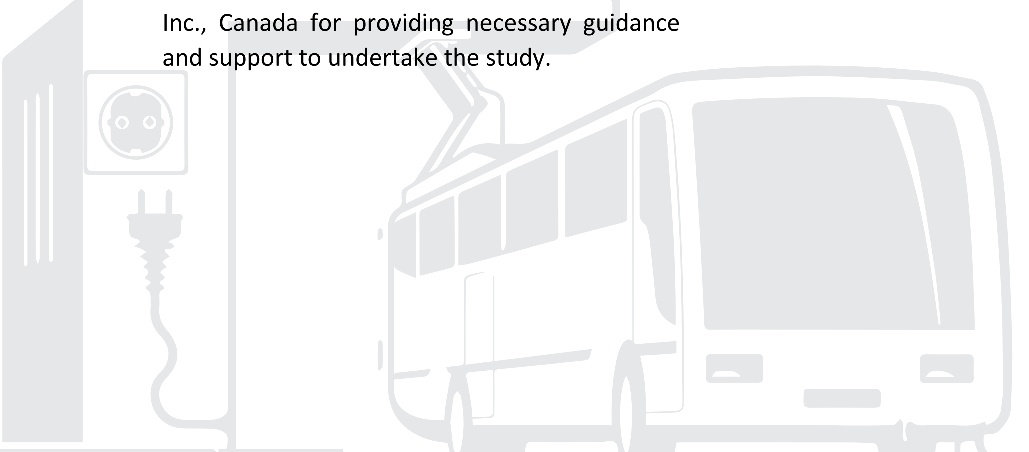
We would like to thank Mr. N Venugopal Rao, Vice President, Olectra Greentech Limited, and the Olectra team for providing the necessary support to undertake the study in Pune.

We would like to thank Mr. Debasish Banerjee, Managing Director, CESC Limited and the CESC team for providing the necessary assistance required for this study in Kolkata.

We would like to thank Trident Tech Labs Pvt Limited., for helping us with the load-flow studies of the distribution network feeders in Pune and Kolkata bus depots.

We would like to thank Mr. Shahzad Alam and Mr. Saurabh Tripathi from Solvina India Private Limited for providing the Power Quality Meters and help with analysis of the data for the study.

We also like to extend our sincere gratitude to all other stakeholders for their cooperation and support during the course of this study.



Preface

Reji Kumar Pillai
President, India Smart Grid Forum
Chairman, Global Smart Energy Federation

We are pleased to present this report on the detailed study conducted on the electrical safety and power quality impacts on the electric grid while charging of electric vehicles, particularly large fleets of electric buses. This is a first of its kind study anywhere in the world in which actual measurements from two power quality meters installed at two bus depots were captured for nearly one year and the results analyzed as well as modelled different future scenarios of load growth. The average electrical load at the Pune bus depot where 100+ electric buses are charged is in the range of 4-5 MW; while in the bus depot in Kolkata has only 8 buses and the cumulative charging load there is 480 kW. Both the power quality meters from Metrum, Sweden and leased for this study by Solvina, who also helped with the power quality analysis. The study has brought out several important findings related to frequent voltage swings and rapid voltage changes taking place in the grid which need further studies. It is observed that the harmonics are presently within the limits prescribed in the relevant standards in both Pune and Kolkata bus depots. However, when more EV charging loads are added in these locations, power quality studies must be undertaken; and if required harmonic filters to be installed.

Government of India has launched a program to rollout of 50,000 electric buses in the next 3-4 years which would require MW-scale power connections in thousands of bus depots across the country, particularly to bus depots in congested cities where limited space is available for expansion of electrical substations and new cabling. This would require detailed planning in close coordination between the road transport undertakings, electric bus fleet operators, electricity distribution companies and the municipal agencies. This study report and the recommendations herein would be helpful for such planning and implementation of charging infrastructure in the bus depots.

We wish all the best to all the stakeholders in electrification of public transportation in India.

REJI KUMAR PILLAI

ISGF
India Smart Grid Forum

India Smart Grid Forum (ISGF) is a Think-Tank of global repute on Smart Energy, Electric Mobility and Smart Cities. ISGF, established as a Public Private Partnership initiative of Government of India in 2011, is spearheading the mission to accelerate electric grid modernization and energy transition in India. ISGF is registered as a Not-for-Profit Society under Indian Societies Act. The main objectives of ISGF are to conduct research and studies on evolving technologies related to energy transition, electric mobility, and electric grid modernization relevant in the Indian context through case studies, cost-benefit analysis and other ancillary activities. ISGF also brings together experts from policy, regulation, academia, and the industry to formulate and support enabling policies, standards and regulations.

“For private circulation only”

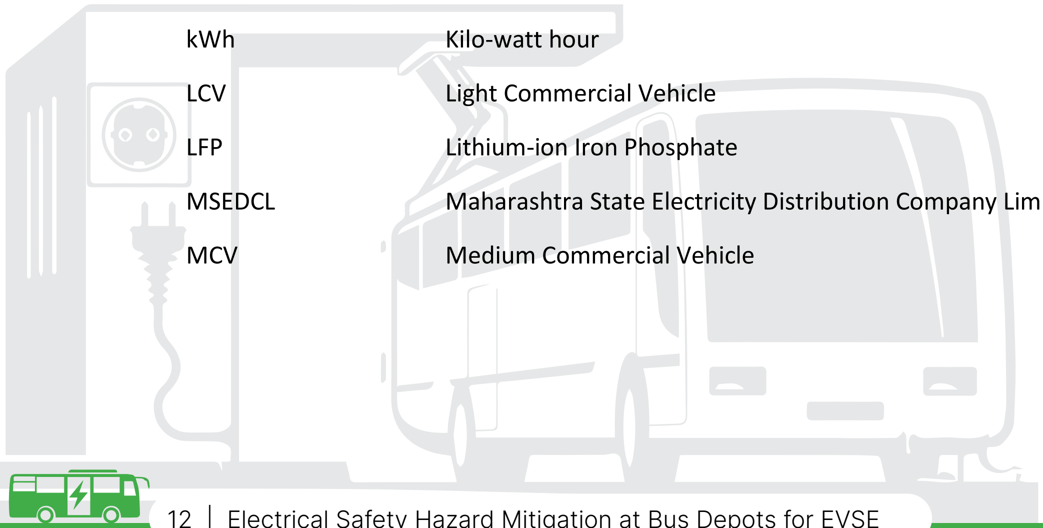
Contents

List of Figures

List of Tables

Abbreviations

AC	Alternating Current
BIS	Bureau of Indian Standards
CO$_2$	Carbon Dioxide
CEA	Central Electricity Authority
CCS	Combined Charging System
COP	Conference of the Parties
DHI	Department of Heavy Industries
DC	Direct Current
DISCOM	Electricity Distribution Company in India
DT	Distribution Transformer
EVSE	Electric Vehicle Supply Equipment
EV	Electric Vehicle
ETD	Electro Technical Division of Bureau of Indian Standards
FAME	Faster Adoption and Manufacturing of Hybrid and Electric Vehicle
GoI	Government of India
GHG	Green House Gas
GDP	Gross Domestic Product
HCV	Heavy Commercial Vehicle
ISGF	India Smart Grid Forum
ITIC	Information Technology Industry Council
IEEE	Institute of Electrical and Electronics Engineers
IEC	International Electrotechnical Commission
IEA	International Energy Agency
kW	Kilo-watt
kWh	Kilo-watt hour
LCV	Light Commercial Vehicle
LFP	Lithium-ion Iron Phosphate
MSEDCL	Maharashtra State Electricity Distribution Company Limited
MCV	Medium Commercial Vehicle



MoHUA	Ministry of Housing and Urban Affairs
MNRE	Ministry of New and Renewable Energy
MoP	Ministry of Power
MoRTH	Ministry of Road Transport and Highways
NABL	National Accreditation Board for Testing and Calibration Laboratories
NEMMP	National Electric Mobility Mission Plan
NSP	Network Service Provider
PCMC	Pimpri-Chinchwad Municipal Corporation
PQ	Power Quality
PQM	Power Quality Meter
PMPML	Pune Mahanagar Parivahan Mahamandal Limited
RE	Renewable Energy
RCD	Residual Current Device
SOP	Standard Operating Procedure
SERC	State Electricity Regulatory Commission
SRTU	State Road Transport Undertakings
WBTC	West Bengal Transport Corporation

Executive Summary

Climate change is one of the greatest challenges humanity is facing now; and its impacts are becoming more obvious: Storms, droughts, fires, and flooding have become worse and more frequent. According to the Intergovernmental Panel on Climate Change's (IPCC) most recent report, the world will suffer grave consequences if greenhouse gas emissions are not completely removed within the next thirty years. India ranks third in the global list in terms of emissions, accounting for 2.46 billion metric tonnes of carbon or 6.8% of the total global emissions. Despite having substantially lower per capita emissions than the global average, its rapid gross domestic product (GDP) development and population expansion constitute serious threat to the environment. The Government of India (GoI) is pursuing different programs for large scale renewable energy (RE) projects and have already achieved 125 GW capacity; and set a new target of 500 GW of non-fossil fuel-based capacity by 2030. In order to decarbonize the transport sector, GoI has set ambitious plans for electrification of public and private transportations.

India is planning to rollout 50,000 electric buses in the next 4-5 years which would require MW-scale power connections at thousands of bus depots across the country, which will require major upgrade to the distribution grid in India and would require proper planning for grid strengthening in coordination with the transport departments and bus fleet operators. Electric vehicles (EVs) and Electric Vehicle Supply Equipment (EVSE) or chargers uses switch-mode power supplies that converts AC power from the grid to DC power to charge the battery. The process of AC to DC conversion generates harmonics and often increases the neutral current in the network considerably. Chances of overheating of neutral conductor and increasing neutral to earth voltage could affect other electrical equipment or gadgets connected to the network. Detailed studies need to be conducted to assess the extent of impacts of EV charging load on the distribution grid and estimate the mitigation measures to be undertaken along with installation of EVSE in the bus depots. Currently, electric mobility is at nascent stage and therefore, the impact on the grid is not visible, but with the increasing penetration of EVs and charging infrastructure, the impact of charging of EVs on the grid will be significant. To address this issue, ISGF conducted the study of Electrical Safety Hazard Mitigation at Bus Depots for Electric Vehicle Supply Equipment (EVSE). For this study, ISGF selected a bus depot in Pune and another bus depot in Kolkata where power quality meters (PQM) were installed and the real-time readings were captured in a server in ISGF office in New Delhi during the period from August 2021 to August 2022. ISGF also modelled the electrical network in these two depots and conducted simulation studies for different scenarios of bus charging loads in 2022, 2024 and 2027.

Layout of this Report

This study captured and analysed the data recorded by power quality meters installed at Bhekrainagar bus depot in Pune and Lake depot in Kolkata for about one year. The report includes the load flow study and harmonic analysis results of Pune and Kolkata bus depots and recommendations to mitigate the power quality issues occurred due to charging of electric vehicles. Annexures include the number of buses allotted under FAME II, EV policies in various states in India, key requirements for selection of equipment, datasheets of power quality meter, key parameters, standards, and Standard Operating Procedure (SOP) for EVSE in bus depots.

Chapter 1 lays out the objectives of the study and provides context, schemes for promoting electric mobility in India, need for electrification of public transport and various challenges of charging infrastructure. It also elaborates the study objectives, scope, and methodology for the study. **Chapter 2** gives analysis of real time data recorded by the power quality meter installed at Pune bus depot for one year. It also gives the detailed load flow study and harmonic analysis of Pune bus depot for different scenarios: As-Is scenario in 2022, scenarios in 2024 and 2027 considering the load growth and future expansion of electric buses and charging infrastructure. Summary of load flow analysis for Pune bus depot with different cases is mentioned in the table below.

- **Case 1:** For As- Is scenario, connected load of all the EVSEs is considered to perform load flow and harmonic analysis.
- **Case 2:** For As-Is scenario, real time charging load recorded by Power Quality Meter is considered to perform load flow and harmonic analysis.
- **Case 3**: For 2024 scenario, 6% of annual load growth plus the new EVSEs that are likely to be added by 2024 in the bus depot applied on As-Is network to perform load flow and harmonic analysis.
- **Case 4**: For 2027 scenario, 6% of annual load growth plus the new EVSEs that are likely to be added in the bus depot by the 2027 applied to perform load flow and harmonic analysis.

Table ES-0-1: Summary of load flow study of different scenarios – Pune bus depot

Parameter	Case 1: 2022 (With EVSE)	Case 2: 2022 as per PQM Data (With EVSE)	Case 3: 2024 (With New EVSEs)	Case 4: 2027 (With New EVSEs)
Total Source Dispatch (kW)	5633.26	4131.098	8504.84	12678.667
Total EVSE Load (kW) (Including EVSE-AC Load and 6 % Increment/year) (kW)	5479.78	3849.98	8233.60	12301.46
Total EVSE Load in kVA – AC Chargers	5732.43	3940.15	8691.51	12769.173
Total Loss (kW)	153.59	71.40	261.69	377.21
Total EVSE Load (kW) – DC Chargers	5480.00	330.00	1500.00	2190.00
Total Source (kVAR)	1061.66	384.21	1836.43	1517.63
Total Loss (kVAR)	1089.44	412.25	1866.50	1564.41
Number of Overloaded Elements	4	0	15	26
Number of Under-Voltage Elements	0	0	0	0

Chapter 3 gives analysis of real time data recorded by the power quality meter installed at Kolkata bus depot for ten months. It also gives the detailed load flow study and harmonic analysis of Kolkata bus depot for different scenarios: As-Is scenario in 2022, scenarios in 2024 and 2027 considering the load growth and future expansion of electric buses and charging infrastructure. Summary of load flow analysis for Kolkata bus depot with different cases is mentioned in the table below.

- **Case 1**: For As-Is scenario, network is considered without EVSE chargers to perform load flow analysis.
- **Case 2**: For As-Is scenario, network is considered with connected load of all EVSEs to perform load flow and harmonic analysis.
- **Case 3**: For 2024 scenario, 5% of load growth per year with new EVSEs are considered on As-Is network to perform load flow and harmonic analysis.
- **Case 4**: For 2027 scenario, 5% of load growth per year with new EVSEs are considered to perform load flow and harmonic analysis on As-Is network.

Table ES-0-2: Summary of load flow study of different scenarios – Kolkata bus depot

Objective	Case 1: 2022 (Without EVSE)	Case 2: 2022 (With EVSE)	Case 3: 2024 (With EVSE)	Case 4: 2027 (With EVSE)
Peak Load (kW) in Deodar	1546.86	1886.348	2587.81	3966.18
Total Source Dispatch (kW)	1501.08	1501.09	1654.96	1915.80
Total Source Dispatch (kVA)	1583.36	1956.040	2726.89	4281.59
Total EVSE Load (kW) (including EVSE-AC Load and 5 % Increment/year)	0	2188.60	2434.94	3655.80
Total Loss (kW)	45.78	84.98	152.24	309.07
Total EVSE Load (kW) – DC Chargers	0	300.00	780	1740
Total Source (kVAR)	338.04	517.47	881.55	1612.90
Total Loss (kVAR)	50.7	232.18	544.87	1201.58
Number of Overloaded Elements	0	4	11	26
Number of Under-Voltage Sections	0	12	37	86

Chapter 4 presents the analysis of the study and recommendations.

01 Introduction

1.1 Background

Climate change is one of the greatest challenges facing humanity in current times; and its impacts are becoming more obvious: Storms, droughts, fires, and flooding have become worse and more frequent. According to the Intergovernmental Panel on Climate Change's (IPCC) most recent report, the world will suffer grave consequences if greenhouse gas emissions are not completely removed within the next thirty years. India ranks third in the global list in terms of emissions, accounting for 2.46 billion metric tonnes of carbon or 6.8% of the total global emissions. Despite having substantially lower per capita emissions than the global average, its rapid gross domestic product (GDP) development and population expansion constitute serious threat to the environment. The Government of India (GoI) is pursuing different programs for large scale renewable energy (RE) projects and have already achieved 125 GW capacity; and set a new target of 500 GW of non-fossil fuel-based capacity by 2030. In order to decarbonize the transport sector, GoI has set ambitious plans for electrification of public and private transportation.

To achieve sustainable goals set under the climate agreements, India had started its journey towards electrification of transportation in 2013 with the launch of National Electric Mobility Mission Plan (NEMMP) 2020 which envisaged introduction of about 6-7 million electric/hybrid vehicles in India by the year 2020. As part of NEMMP, the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) India scheme was introduced in 2015 to promote electric vehicles (EVs) and EV manufacturing ecosystem. Under the first phase, (FAME I), Department of Heavy Industries (DHI) allocated grant for 390 electric buses, 370 electric taxis, and 720 electric three-wheelers to 10 cities with a total investment of INR 5.37 billion.

Table 1-1: DHI allocated vehicles for 10 cities under FAME scheme

Sl No	Cities	Electric Buses	e-Taxis	3-Wheelers
1	Kolkata	80	200	-
2	Ahmedabad	40	20	20
3	Bengaluru	40[1]	100	500
4	Jaipur	40	-	-
5	Mumbai	40	-	-
6	Lucknow	40	-	-
7	Hyderabad	40	-	-
8	Indore	40	50	200
9	Jammu	15	-	-
10	Guwahati	15	-	-
Total		**390**	**370**	**720**

Source: DHI

The FAME scheme was extended in 2019 as FAME II for the next three years; and has now been further extended by another two years till March 31, 2024, with a total outlay of INR 100 billion in order to support the development of both EV and EV charging infrastructure by providing support in terms of

---

[1] Since Bangalore did not procure electric buses under FAME I, those 40 buses were allocated to Kolkata where original allocation was only 40 buses.

incentives to EV buyers, state power and transport utilities. 86 percent of FAME II funds has been allocated for demand side incentives for 7,000 electric buses, 5,00,000 electric three-wheelers, 55,000 electric four-wheelers and 1 million electric two-wheelers.

State and municipal governments have also started initiatives to accelerate the electrification of transport sector. So far 23 states have issued electric vehicle policies. State Road Transport Undertakings (SRTUs), smart cities mission-driven special purpose vehicles, and municipalities have already taken impressive steps towards the switch to electric buses. Pure electric or zero-emission vehicles (also called as new energy vehicles in China) are rapidly gaining popularity around the world and are essential for meeting the climate goals.

1.1.1 Need for Electrification of Public Transportation

Globally, the transport sector is responsible for 25% to 30% of total carbon dioxide (CO_2) emissions from fuel combustion. Transportation is the fastest growing sector and a major source of greenhouse gas (GHG) emissions worldwide. Road transportation in India account for 90% of total CO_2 emissions[2] from the transport sector which is the third largest polluting sector in the country. India's GHG emissions were made up of 70% CO_2 and 30% non-CO_2 emissions, which produce local air pollution and lead to a high rate of health consequences and early deaths. Increased transportation emissions will worsen this problem, putting even more strain on an already overcrowded public health system.

Decarbonizing through electrification of India's transportation sector can help to significantly reduce these impacts, as well as provide several additional benefits, such as significant improvements in public health, particularly in cities, reduced oil imports, reduced noise pollution and improved quality of life. As per International Energy Agency (IEA), electrification of the global vehicle fleet of public transport buses will comprise about 30% of projected emission reductions in transport sector by 2050. The electrification of public transport provides an opportunity to achieve low carbon development and the reduction of local air pollution. At the COP 26 in Glasgow in November 2021, GoI has committed following new climate targets:

- India will reach its non-fossil electricity capacity to 500 GW by 2030
- India will meet 50% of its energy requirements from RE by 2030
- India will reduce the carbon intensity of its economy by less than 45% by 2030
- India will reduce the total projected carbon emissions by 1 billion tons from 2021 onwards till 2030
- By the year 2070, India will achieve the target of Net Zero

It is important to note that, even in the absence of a decarbonized power sector, switching to electrified road transport under the sustainable shared socioeconomic pathways provided for a favorable outlook for a low carbon transition.

Case Study: Electrification of Public Transport – The Shenzhen Bus Group

Shenzhen is the only City in the world where all the public buses and taxi fleets are electric. Shenzhen has organized a variety of local schemes for EV adoption and the establishment of charging infrastructure. Close to 500 million yuan (USD 80 million) was spent by the Shenzhen City Government per year from 2009 to 2015 towards subsidy for EVs. As a result, the public buses in Shenzhen are fully electrified by December 2016. Currently, there are 16,359 electric buses in Shenzhen. Apart from the fiscal incentives,

---

[2] IEA, 2020; Ministry of Environment Forest and Climate Change, 2018

Shenzhen has also provided other incentives such as preferential parking spaces and relaxation of registration fee for encouraging EV uptake. As a result, the city is one of the pioneers in the world for the electrification of bus fleets. Significance of this number is to be viewed from the perspective that in 2017, there were only 956 electric buses in entire Europe and less than 500 in entire United States. BYD, one of the leading manufacturers of lithium-ion batteries and electric vehicles including electric buses is headquartered in Shenzhen[3].

Figure 1-1: Buses in Shenzhen eastern bus company's main charging depot in Futian, China

The first step the Shenzhen City Government did was to aggregate bus operations in 3 companies:

Shenzhen Eastern Bus Company Limited: 16 private bus operators were integrated and made Shenzhen Eastern Bus Company Limited which is fully owned by the Shenzhen City Government. Today they operate 5,805 electric buses.

Shenzhen Bus Group: This Company was owned by Shenzhen City government. They operate 5,600 electric buses.

Shenzhen Western Bus Company Ltd: This is still privately owned and they operate about 4,400+ electric buses.

Electric buses deployed in Shenzhen City are mostly 10.5 meter in length, seating capacity of 32 plus with 20-30 passengers standing. But at times in some routes 80+ people may be on board. Buses have Lithium-ion Iron Phosphate (LFP) battery of 252 kWh which ensure minimum 200 km driving range per full charge and are charged with BYD supplied 2*40 kW (3 Phase, 415 Volt) AC chargers installed in the bus depots. Bus charging in the depots is under industrial tariff. During the 8 hours of off-peak tariff (11PM to 07AM), all buses are fully charged.

After completion of electrification of the bus fleet in Shenzhen, in the very first year itself 39,000+ private cars were removed from daily usage from city roads.

---

[3] ISGF Report: Electric Bus Revolution of Shenzhen City in China

1.1.2 National Target for Bus Electrification

With the growing focus of the GoI to transform the public transportation landscape in the country, several ministries and departments including the Ministry of Road Transport and Highways (MoRTH), Department of Heavy Industries (DHI), Ministry of Finance (FM), Ministry of Housing and Urban Affairs (MoHUA), Ministry of Power (MoP), Ministry of New and Renewable Energy (MNRE), NITI Aayog and multiple stakeholders. have come up with various guidelines and roadmaps to accelerate the growth of electric mobility in the country. Governments at the national, state, and local levels as well as industry regulators are primarily responsible for creating a holistic ecosystem and supporting it with policies and regulations. Several companies such as Olectra (Indian partner of BYD), TATA Motors, Switch Mobility (Ashok Leyland), JBM Group and PMI are manufacturing electric buses in India.

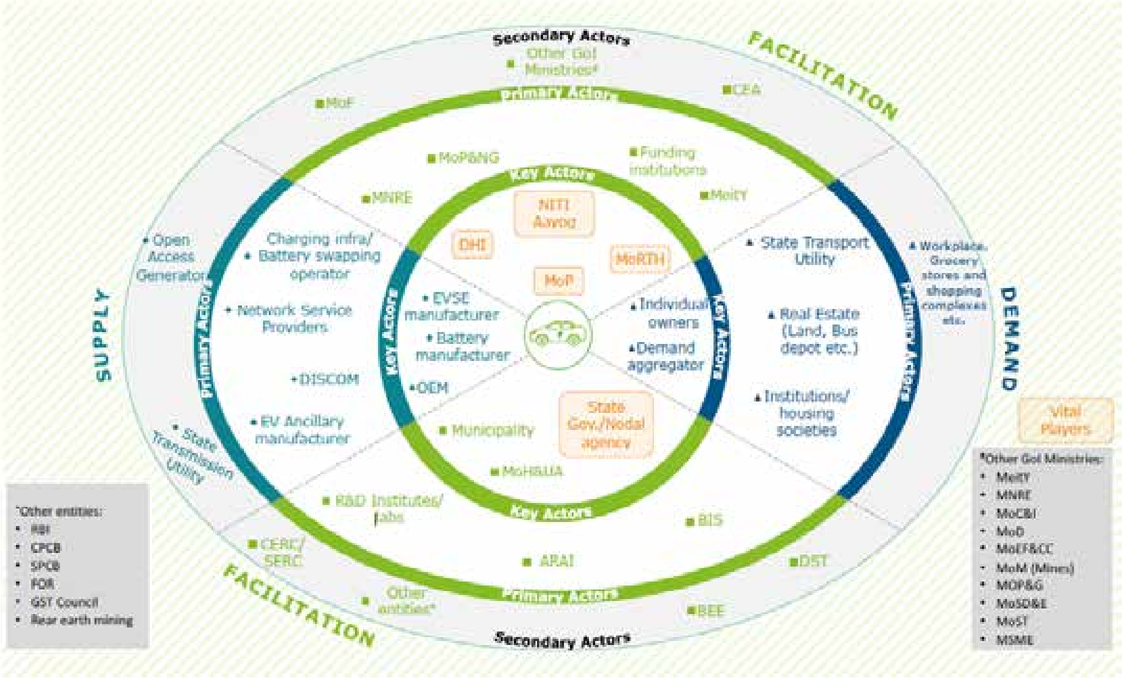


Figure 1-2: Ecosystem of electric mobility in India[4]

As already mentioned, DHI allocated 390 electric buses under the first phase of FAME; and under FAME II, DHI allocated 5,595 buses[5] to 64 cities for intra-city and intercity operations. Metropolitan cities like Delhi, Mumbai, Hyderabad, Bengaluru, and Ahmedabad have been allocated 300 buses each. For intercity operations, 400 buses are sanctioned to eight state transport undertakings with 50 buses each and Delhi Metro Rail Corporation has received 100 buses for ensuring last mile connectivity in Delhi/NCR. The list of cities and number of buses allocated under FAME II is given in Appendix I.

The National Electric Bus Programme (NEBP) launched by Government of India aims to deploy 50,000 new electric buses in the near future, of which rural and intercity buses are expected to form a significant share. Tentative requirement of bus depots to accommodate the 50,000 e-Buses shall be around 800-1200 Nos. In 2022 Convergence Energy Services Limited (CESL) floated a tender of 5,450 electric buses in

---

[4] Report by GIZ - Status quo analysis of various segments of electric mobility and low carbon passenger road transport in India - Deloitte analysis

[5] DHI - https://bit.ly/3nLFF0q

5 cities under Gross Cost Contracting (GCC) model. The contract was subsequently awarded in July-August 2022 by respective State Transport Utilities (STUs) to the successful bidders. Subsequently, another tender was released in September 2022 by CESL for additional 5,690 electric buses under GCC model.

DHI allotted 2,636 charging stations (1,633 fast-charging stations and 1,003 slow charging stations) for 62 cities across 24 States/UTs under FAME II[6] which is given in the Table below. GoI aims to cover highways as well and establish charging stations on both sides of the road with a gap of 25 km between two consecutive stations; and the target is to have at least one public charging station (PCS) in a 3 km x 3 km area.

Table 1-2: State-wise allocation of EV charging stations across India

Sl No	States/UTs	No. of EV Charging Stations Allocated	Sl No	States/UTs	No. of EV Charging Stations Allocated
1	Maharashtra	317	13	Chandigarh	70
2	Andhra Pradesh	266	14	Haryana	50
3	Tamil Nadu	256	15	Meghalaya	40
4	Gujarat	228	16	Bihar	37
5	Rajasthan	205	17	Sikkim	29
6	Utter Pradesh	207	18	Jammu & Kashmir	25
7	Karnataka	172	19	Chhattisgarh	25
8	Madhya Pradesh	159	20	Assam	20
9	West Bengal	141	21	Odisha	18
10	Telangana	138	22	Uttarakhand	10
11	Kerala	131	23	Puducherry	10
12	Delhi	72	24	Himachal Pradesh	10
Total					**2,636**

Policies and regulations are essential to help the development of the ecosystem for electric mobility as EVs are still in their infancy. The focus of policy and regulatory actions around the world has been on offering different fiscal and non-fiscal incentives to encourage the adoption of EVs and establishment of charging infrastructure. In order to encourage the localization of EV components production, India has also established the national goal of 30% EV market penetration by 2030. Several states have notified their EV policies for encouraging EVs, which include tax exemptions and subsidies for consumers/buyers in addition to the different central level initiatives. Till date, total of 22 states have notified their EV policies viz. Andhra Pradesh, Assam, Bihar, Chandigarh, Delhi, Goa, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Odisha, Punjab, Rajasthan, Tamil Nadu, Telangana, Uttar Pradesh, Uttarakhand and West Bengal. The detailed policy incentives of 22 states across India are given in Appendix II.

In December 2016, ISGF made a presentation to Forum of Regulators (FoR) and advocated for separate tariff for EV charging in order to promote Electric mobility in the country. In 2017, Delhi Electricity Regulatory Commission (DERC) for the first time introduced a separate tariff category for EV charging which they further fine-tuned in 2018. Many State Electricity Regulatory Commissions (SERCs) have notified separate EV tariff that is to be charged by DISCOM to EV charging station operators. As of April

---

[6] Press Information Bureau, Government of India: https://bit.ly/3joa0Ra

2023, 23 states have issued separate electricity tariffs for EV charging in India. The below Table presents EV tariffs of various states in India.

Table 1-3: EV tariff structures for the various states in India

Sl No	State/UT	EV Tariff	Capacity Charges	Sl No	State/UT	EV Tariff	Capacity Charges
1	Andhra Pradesh	INR 6.7/kWh	No Capacity Charges	13	Kerala	INR 5/kWh	LT: INR 70/kW per month HT: INR 250/kVA per month
2	Assam	INR 5.25/kWh to INR 6.75/kWh	LT: INR 130/kW per month HT: INR 160/kVA per month	14	Madhya Pradesh	INR 5.9/kWh to INR 6/kWh	INR 100 to 120/kVA per month
3	Bihar	INR 6.32/kWh to INR 7.4/kWh	No Capacity Charges	15	Maharashtra	INR 4.05/kWh to INR 4.24/kWh	INR 70/kVA per month
4	Chhattisgarh	INR 5/kWh	No Capacity Charges	16	Meghalaya	INR 10.09/kWh	INR 100 to 230 per connection per month
5	Chandigarh	INR 4/kWh to INR 4.1/kWh	No Capacity Charges	17	Orissa	INR 4.2/kWh to INR 5.7/kWh	No Capacity Charges
6	Delhi	INR 4.5/kWh	No Capacity Charges	18	Punjab	INR 5.4/kWh	No Capacity Charges
7	Goa	INR 4.2/kWh	No Capacity Charges	19	Rajasthan	INR 6/kWh	INR 135/kVA per month
8	Gujarat	INR 4/kWh to INR 4.1/kWh	INR 25 to 50/kVA per month	20	Tamil Nadu	INR 5/kWh to INR 8.05/kWh	INR 70/kVA per month
9	Haryana	INR 6.2/kWh	INR 100/kW per month	21	Telangana	INR 6/kWh	No Capacity Charges
10	Himachal Pradesh	INR 4.7/kWh to INR 5/kWh	INR 130/connection per month and INR 140/kVA per month	22	Uttar Pradesh	INR 5.92/kWh to INR 7.7/kWh	No Capacity Charges
11	Jharkhand	INR 6/kWh to INR 6.25/kWh	INR 40 to 150/connection per month	23	Uttarakhand	INR 5.5/kWh	No Capacity Charges
12	Karnataka	INR 5/kWh	INR 60/kW per month				

1.1.3 Charging Infrastructure – Challenges

Number of EVs being sold in all categories - two, three and four wheelers - have multiplied in the recent years. Building enough charging stations at convenient locations and strengthening the electric grid to support trouble-free charging are key facilitators for accelerating e-mobility. One of the key concerns of EV buyers is the availability of recharging facilities at convenient places. The terminology used is "range anxiety," which refers to the dread that a vehicle's energy in the battery will be insufficient to traverse the distance to the destination.

In terms of development, the EV charging infrastructure confronts various hurdles as listed below:

- **High Initial Investment:** The capex for setting up an EV charging station is high. The requirements to build the EV charging stations include land availability at appropriate locations, chargers or EVSE at right prices and required electricity connection and uninterrupted supply of electricity. Because the cost of installing an EV charging station is high and the fee from charging EVs alone is not sufficient for return on investment, innovative business models are necessary to support charging station operators.
- **Multiple Types of Charging Connectors:** The IS:17017 series of standards for EVSEs issued by the Bureau of Indian Standards (BIS) allow both CCS 2 and CHAdeMO type of DC chargers besides AC type 2 chargers. EVSEs conforming to Bharat Charger Specifications issued by DHI are also allowed in India. So, charging station operators have the freedom to install all or any of these chargers depending on the business volume. The most critical factor for the installation of charging stations is investment related to electricity connection. At certain locations the existing distribution network could provide 50 kW or 100 kW or 200 kW connections depending on the headroom available in the nearest distribution transformers (DTs). But in many places, such connections would require installing a new DT and cabling, which can be prohibitively expensive considering the very high municipal charges for cabling.
- **Location to Set Up the EV Charging Station:** The land or space at appropriate location is a major challenge for installing EV charging stations. The charging station should be located or planned in such a manner that it is clearly visible, accessible, saves time, and reduces the charging queue. For this reason, the location should be a desirable position with adequate parking space, accessibility, ease of setup and convenient waiting area for customers to wait.
- **Technical Safety at EV Charging Stations:** The installation of electric vehicle charging stations necessitates a high level of technical expertise. Major problems include voltage fluctuations, over current, frequency mismatch, and ground fault. Stabilizers, proximity sensors, and control pilot sensors must all be combined to keep voltage fluctuations under control. Otherwise, the expensive components in the EVSE may be damaged. Many concerns, such as power issues, heat dissipation, grounding, and voltage monitoring, can be resolved by properly designing the hardware components.
- **Software Related Challenges:** Locating the nearest charging station and finding the availability of a charging slot is one of the most crucial tasks. Several software apps are in use; but no one app so far in India on which one can locate all the charging stations.

Access to public charging need to expand as EV adoption grows. The majority of EV charging now takes place at residences. Consumers will increasingly expect EVs to provide the same services conventional vehicles. At the end of 2022, there were 2.7 million public charging points worldwide, more than 900,000 of which were installed in 2022, about a 55% increase on 2021 stock, and comparable to the pre-pandemic growth rate of 50% between 2015 and 2019. Globally, more than 600,000 public slow charging points and

330,000 fast charging points were installed in 2022, 360,000 of which were in China, bringing the stock of slow chargers in the country to more than 1 million. China was home to more than half of the global stock. The global EV fleet consumed about 110 TWh of electricity in 2022.

Over the past few years, there has been a rapid increase in the number of EVs on the road and in operation in workplaces (including warehouses and industrial sites). Given the environmental initiatives by Government, this is likely to continue over the next several years, along with correspondingly increasing need for charging stations. To ensure electrical safety and prevent hazardous incidents, a number of safety standards are developed, with the safety requirements for EVSE and the EV battery serving as the two main driving forces.

Based on the request by ISGF in 2016, Bureau of Indian Standards (BIS) constituted Electrotechnical Division (ETD) 51 Committee for drawing Indian standards for EVSE. ETD 51, chose to adopt the IEC standards as the primary standards for EVSE in India. BIS has already issued IS 17017 Part 1 in 2018; and several accompanying standards published in the last four years. The status of the standards is given in Chapter 4.

EVSEs have different power ratings or levels based on charging requirements, which in turn determine the input power requirements for charging infrastructure. Below Table categorizes EV charging by power level, with normal power charging going up to 22 kW and high-power charging going up to 240 kW. While EVSEs with power ratings up to 500 kW are globally available, they are largely applicable for heavy vehicles like buses and trucks.

Table 1-4: EVSE power ratings

	Power level	Current type	Compatible EV segments
Normal Power Charging	≤ 7 kW	AC and DC	E-2Ws, e-3Ws, e-cars, other LCVs (up to 1 ton)
	7 ~ 22 kW	AC and DC	
High Power Charging	22 kW ~ 50 kW	DC	E-cars, LCVs and MCVs (1-6 tons)
	50 kW ~ 240 kW	DC	

EVSE selection for the charging station must be in line with the government guidelines. For public charging stations (PCS), Ministry of Power (MoP) notified revised guidelines in the month of January 2022. Key requirements mentioned therein are summarized below:

- The PCS should have an exclusive transformer with all related substation equipment including safety appliances
- The PCS should include 33/11 kV lines/cables and associated equipment including line termination etc.
- The PCS must have appropriate cabling, electrical and civil work ensuring safety
- The PCS providers are free to create charging hubs and to install additional number of kiosk/chargers in addition to the minimum number of chargers as prescribed
- Share charging station data with appropriate DISCOM and to maintain appropriate protocols as prescribed by such DISCOM for this purpose; and Central Electricity Authority (CEA) shall have access to this database
- EVSE shall be type tested by a third-party lab accredited by National Accreditation Board for Testing and Calibration of Laboratories (NABL)
- The PCS must tie up with at least one online Network Service Provider (NSP) to enable advance remote/online booking of charging slots

- Current international standards that are prevalent and used by most vehicle manufactures internationally are CCS and CHAdeMO. Hence, public charging stations must have one or more electric kiosks/boards with the installation of all the charger models, as shown in below

Table 1-5: Public charging infrastructure requirements

Sl No	Charger Type	Charger Connectors	Rated Output Voltage (V)	No. of Connector Guns (CG)	Charging Vehicle Type
1	Fast	CCS (min 50 kW)	200-750 or higher	1	4-Wheelers
2		CHAdeMO (min 50 kW)	200-500 or higher	1	4-Wheelers
3		Type-2 AC (min 22 kW)	380-415	1	4-Wheelers, 3-Wheelers and 2-Wheelers
4	Slow/Moderate	Bharat DC-001 (15 kW)	48	1	
5		Bharat DC-001 (15 kW)	72 or higher	1	
6		Bharat AC-001 (10 kW)	230	3 guns of 3.3 kW each	

Source: MOP

Table 1-6: Charging power and energy requirements of different segments

Vehicle Type	Typical Battery Sizes	Slow Charging	Fast Charging
2-W	1-3 kWh	0.5-1 kW	2-3 kW
3-W	3-7 kWh	0.5-1 kW	2-3 kW
4-W	15-90 kWh	3 kW	50-240 kW
Buses	100-400 kWh	40-80 kW	50-500 kW
Trucks	200 -600 kWh	40-80 kW	50-500 kW

Other than the regulations and standards set by the GoI, there are number of other things to consider while choosing an EVSE. Some of the requirements are mentioned in the Appendix III.

As mandated by policy, the charging station should be inspected by the relevant authority prior to going into commercial operations. The authority assesses the charging station on a number of criteria in accordance with the relevant CEA rules or international standards. For safe operation and maintenance of charging stations it is important to focus on some of the parameters like protection, harmonic current, injection, voltage sag, voltage swell, flicker, disruptions, overload, lightning protection, protective device, disconnection of EV from the supply, locking of the coupler, protection against overvoltage at the battery. Some of the parameters, reference standards, specified limits and actionable items required for safe operation and maintenance of EV charging stations[7] are presented in Chapter 4.

---

[7] GIZ Report on Status quo analysis of various segments of electric mobility and low carbon passenger road transport in India, 2022

1.2 Objectives and Scope of the Study

New Venture Fund (NVF) supported India Smart Grid Forum (ISGF) to conduct this detailed study related to “Electrical Safety Hazard Mitigation at Bus Depots for Electric Vehicle Supply Equipment (EVSE)”.

The study objectives are:

- To avoid accidents in bus depots while charging of electric buses
- To avoid lost opportunity in abating GHG emissions
- To avoid electrical infrastructure losses
- To ensure the safety of the operation and maintenance (O&M) personnel
- To avoid discomfort due to power outages in the aftermath of the hazards

The scope and activities undertaken for this project are listed below:

Table 1-7: Scope of the project

Sl No	Scope	Activities
1	Need of electrification of public transportation	This has been articulated in the Chapter 1 of this report (1.1.1).
2	Install power quality meters (PQM) in 2 bus depots and study the impact of electric bus charging on the low voltage grid	Metrum make PQMs were installed in Pune and Kolkata bus depots; and the measurements recorded in the PQMs were transmitted to a server installed in ISGF office in real-time. This is described in detail in Chapter 2 (Pune) and Chapter 3 (Kolkata) of this report.
3	Assessment of power quality measurements using the power quality meter installed at Pune and Kolkata bus depots	
4	Load flow analysis of bus depots located in Pune and Kolkata	This is described in detail in Chapter 2 (Pune) and Chapter 3 (Kolkata) of this report.
5	Assessment of the impact of electric bus charging on the distribution grid	This is described in detail in Chapter 2 (Pune) and Chapter 3 (Kolkata) of this report.
6	Assess the measures taken in international scenarios for the safe installation, operation, and maintenance of EVSE	Case study of Shenzhen City is covered in Chapter 1 of this report. Recommended safe practices for Installation, Operation and Maintenance of EVSE is given in Chapter 4 of this report.
7	Assessment of safe operation and maintenance of Electric Vehicle Supply Equipment (EVSE)	
8	Undertake simulation studies to determine the level of harmonic filters and other protection equipment required for safe operation of electric bus charging stations	Load flow studies carried out for Pune and Kolkata and the details are provided in Chapter 2 (Pune) and Chapter 3 (Kolkata) of this report.
9	Review the need of active or passive harmonic filters and other mitigation measures	This is covered in Chapter 2 (Pune) and Chapter 3 (Kolkata) of this report.
10	Enlist the standards to be followed for installation of EVSE	This is described in Chapter 4 of this report.
11	Gauge the role DISCOMS can play to avoid hazards in the future	

12	Standard Operating Procedure (SOP) for EVSE maintenance; and recommendations for DISCOMs and bus operators	
13	Convene the relevant stakeholders to disseminate the findings	A WebEx seminar is being organized in May 2023.

1.3 Study Methodology

The study was conducted according to the following methodology:

Step 1: Conducting the As-Is Assessment

Regulatory guidelines for electrical infrastructure required for charging station implementation issued by MoP along with state regulatory guidelines on electricity distribution and protection arrangement for charging stations studied to understand the existing scenario across various states in India.

Step 2: Installation of Power Quality Meter (PQM)

ISGF studied the scenario of available EV charging stations and its infrastructure for electric buses in India and selected two bus depots namely PMPML’s Bhekrainagar bus depot in Pune and Lake bus depot of WBTC, Kolkata. ISGF installed PQM at these two bus depots to monitor and analyse the impact of electric bus charging on the electrical grid.

Step 3: Analysis of PQM Readings

The data captured by PQMs installed at two bus depots located in Pune and Kolkata are analyse and based on the charging of electric buses, the impact of the electrical grid is monitored with reference to the various electrical parameters like harmonics, current, voltage profiles, sag, and swell, etc.

Step 4: Modelling Studies in Two Bus Depots

ISGF collected data from bus depot related to charging infrastructure and bus charging pattern and also visited the electrical substations and collected the data on electricity distribution infrastructure in bus depots and the substation feeders. ISGF modelled the electrical distribution systems and the chargers on simulation software and studied the load flow analysis and harmonics. This model was used to determine the level of harmonic filters and other protective equipment required for the safe operation of electric bus charging stations in 2022, 2024 and 2027. It also analysed the impact of electric bus charging on the low voltage grid and the need for harmonic filters.

Step 5: Modelling Events Captured by PQM

ISGF installed PQM at two bus depots in Pune and Kolkata and the events captured by these PQMs were modelled considering the severity of the events and charging patterns of the electric buses. As per the events captured by the PQM are compared with the log book of the charging operations maintained in the respective bus depots.

Step 6: Analysis and Evaluation of PQM Readings and Modelling Studies

The PQM data has been analysed and the critical events have been simulated on the load flow model. Also, the model was used to simulate and predict different scenarios of EV charging load growth in future.

Step 7: Recommendations

Recommendations as per the scope of the project are presented in the Chapter 4 of this report.

02 Power Quality Measurement Studies at PMPML Bus Depot in Pune

Similar to any other commodity, electrical energy must adhere to the necessary quality standards in order to be considered for safe usage. Electrical energy must be provided at a voltage within a specific range around the rated value for electrical equipment to function properly. Today's technology is heavily dependent on quality power at constant voltage and frequency particularly for electronic, communication and IT equipment. While the grid supplies alternating current (AC), it is converted to direct current (DC) at customer premises for a variety of appliances including charging of electric vehicles. When AC is converted to DC, it causes distortions in voltage supply (non-linear characteristics because it draws a non-sinusoidal current with a sinusoidal supply voltage). As a result, the utility and the customer who convert AC to Dc should share the responsibility for ensuring satisfactory power quality.

The following standards gives general limits for power quality to be maintained:

- European Standard – EN 50160
- International Electrotechnical Commission - IEC 61000-4-30
- The Institute of Electrical and Electronics Engineers - IEEE 519
- Swedish Power Quality Standard - EIFS 2013:1

Power Quality (PQ) has two aspects – voltage and current which are directly linked to each other. Power factor, harmonics, phase-imbalance, and neutral current are the four factors that can be used to describe power quality for current. The impact of load characteristics on the grid can be evaluated using these four metrics. The main issues with voltage are phase-imbalance, sags, swells, and interruptions, etc.

PQ is important to safeguard the proper functioning of the power system and the loads (equipment and appliances) connected to it. PQ requirements should be characteristics of both parts of the power system - the energy supplied by the grid, as well as the energy consumed by the equipment connected to the grid.

Multiple switch mode power supply (SMPS) units are used by electric vehicle charging stations to convert AC power to DC power in order to charge batteries. This conversion process produces harmonics, particularly in the 3rd, 5th, and 7th order. The third harmonics accumulate in the neutral and are not cancelled at the star point, greatly boosting the neutral current. This causes the neutral to overheat and raises the neutral to earth (NE) voltage, which could pose a serious risk to nearby electronic devices. The majority of the load distribution is also balanced, but due to unpredictable charging patterns, there could be sudden imbalance between the three phases. These are the main issues with power quality brought on by EV chargers.

ISGF installed power quality meter of Metrum make (PQ140 class A) at 22 kV substation of Maharashtra State Electricity Distribution Company Limited (MSEDCL) situated in Bhekrainagar Bus Depot of Pune Mahanagar Parivahan Mahamandal Limited (PMPML). Power quality analysis is done as per EN 50160.

2.1 EVSE Installed in Pune Bus Depot

PMPML is the public transport bus service provider in the Pune Metropolitan Region. PMPML was formed on 19 October 2007 when two bus service providers, Pune Municipal Transport and Pimpri-Chinchwad

Municipal Transport, merged into a single entity. PMPML is jointly owned by Pune Municipal Corporation and Pimpri-Chinchwad Municipal Corporation in a 60:40 ratio. PMPML plans to induct 650 electric buses in its fleet of around 2,000 buses to ensure that the public transport bus service is environment-friendly. Currently, PMPML has a fleet of 150 electric buses which are charged at five depots located at Bhekrainagar, Baner, Nigadi, Pune station and Wagholi.

At Bhekrainagar bus depot, PMPML installed 5 transformers of 1250 kVA each as packaged substations (PSS). Total 58 AC chargers of 80 kW capacity (with 2 guns of 40 kW each) and 5 DC chargers (2 of 150 kW and 3 of 180 kW) are installed. Bhekrainagar bus depot is running at its full capacity and more than 100 electric buses are charged there. The layout of charging infrastructure at Bhekarinagar bus depot with charger capacity is given below:

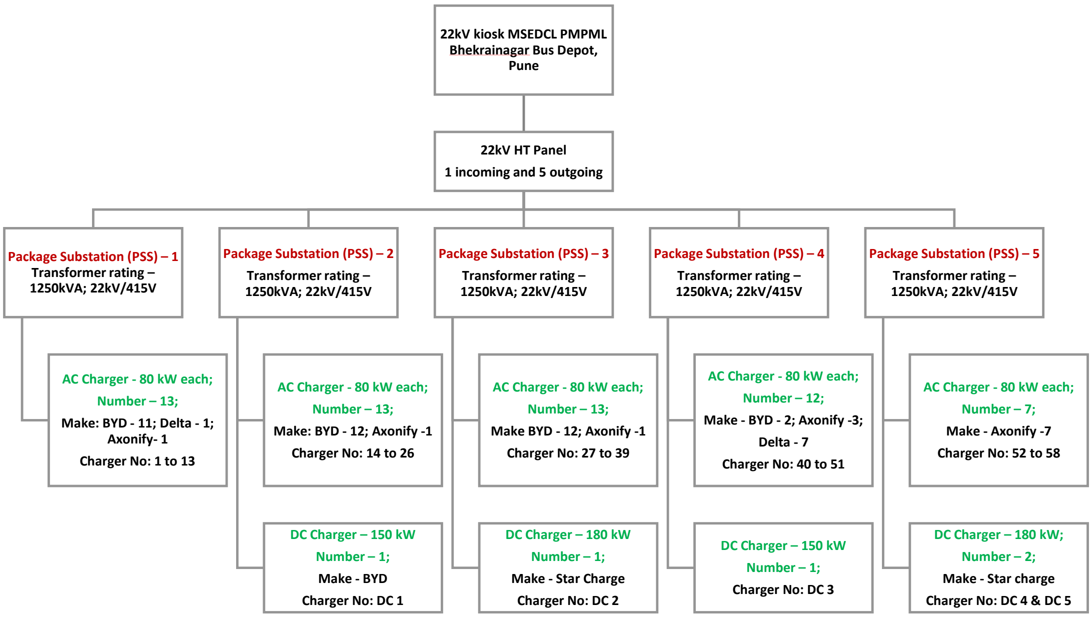


Figure 2-1: Layout of the chargers at Bhekrainagar bus depot, Pune

Figure 2-2: Chargers installed at PMPML Bhekrainagar bus depot, Pune

Figure 2-3: EVSE installed at PMPML Bhekrainagar bus depot, Pune

2.2 Power Quality Meter (PQM) Installed at Pune

After analysing the specifications and features of different makes of PQM for this study, ISGF chose the PQM of Metrum, Sweden. In Pune, ISGF installed Metrum PQM 140 Class A leased for one year through Solvina, Sweden. Metrum PQ instruments are developed to perform according to IEC 61000-4-30 Class A requirements as below:

- Measurement accuracy: Error < ±0.1%
- Each parameter defined with requirements for algorithms, methods, sampling frequency

- Sags, swells, and interruption measurement on each measurement period updated on each half cycle

The Metrum's instruments of the PQ-series are specifically designed for normative measurements in the electrical grid of utilities and industries. The main advantage of having a Class A reference instrument is that it can be used for all measurements where the result will be compared with other instruments. The measurement and limits for this study are set as per European Standard, EN - 50160. The datasheet of PQ 140 is attached in the Appendix IV.

Figure 2-4: Power quality meter - PQ140

2.3 PQM Connection Diagram

The PQ140 installed at the metering point (check meter) of 22 kV connection provided by MSEDCL, Pune at PMPML Bhekrainagar bus depot, where more than 100 buses are being charged on daily basis. The PQ meter gives records and measurements of the grid disturbances and impact of EV charging loads on power quality and discrimination between disturbances caused from downstream (due to EV charging operations) or upstream (from the grid substation). The analysis includes important power quality parameters like harmonics, sag and swell, voltage variations etc. occurred on the network and their effects.

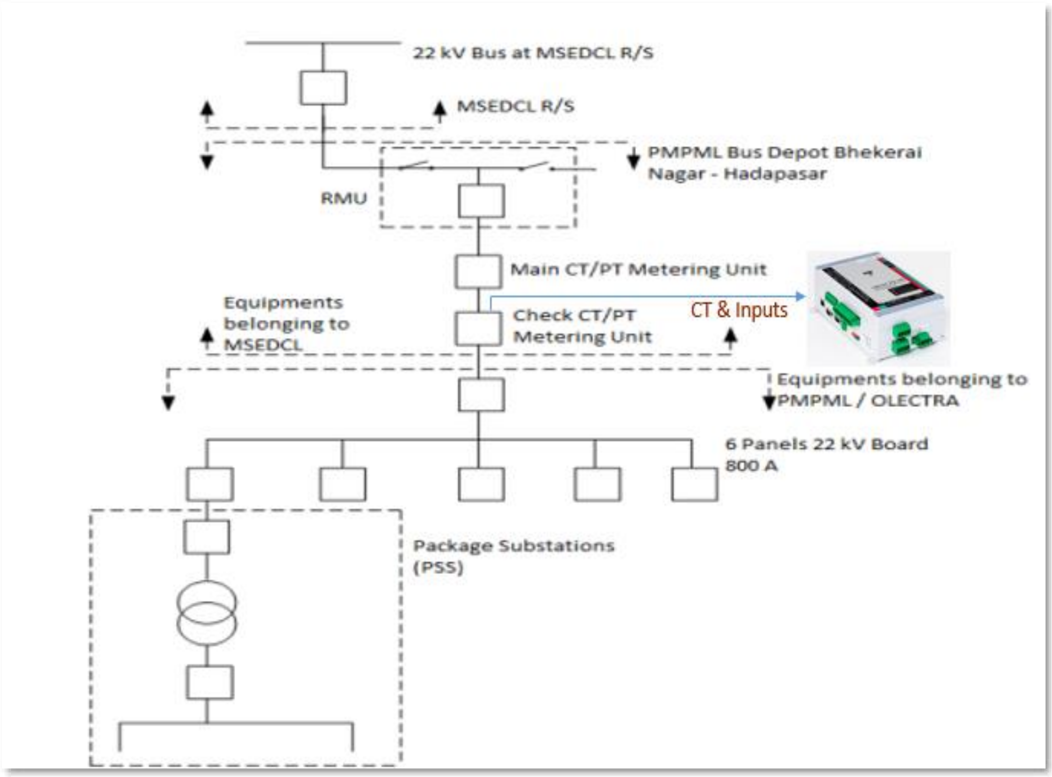


Figure 2-5: Connection diagram of PMPML Bhekrainagar bus depot, Pune

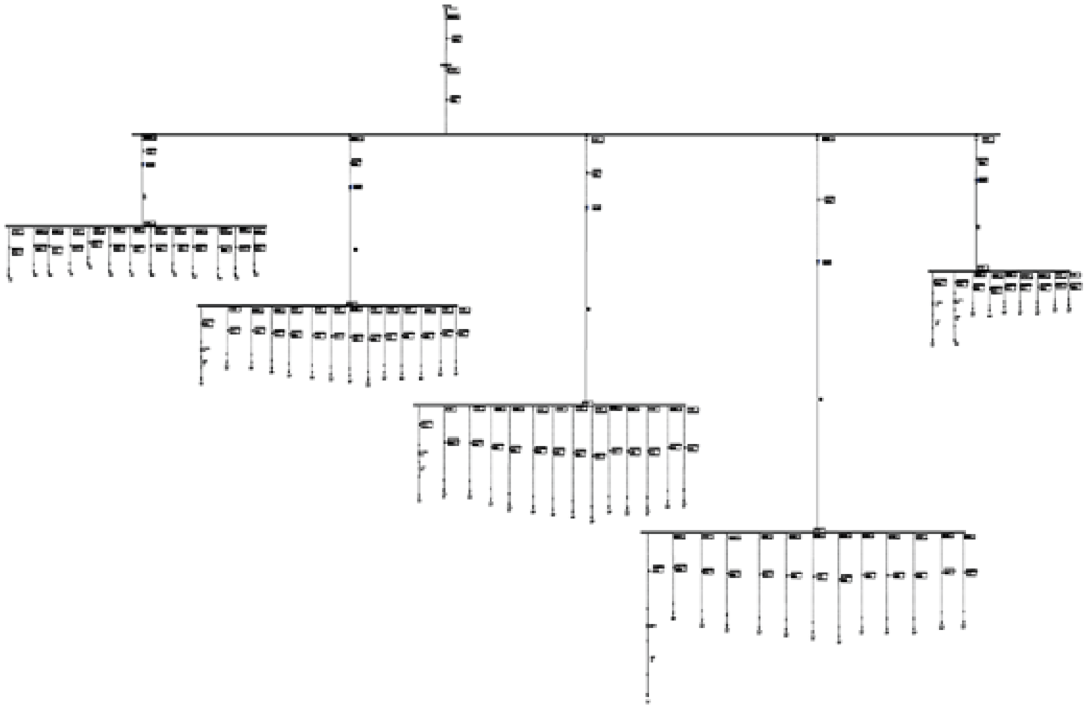


Figure 2-6: SLD of PSS and chargers connected to each PSS

Figure 2-7: Installed PQ meter at 22 kV substation

2.4 PQM Measurements and Observations

2.4.1 Voltage Sags

Voltage sags are the most common events that affect power quality. These are harmful for the electronic devices used in EVSE and EVs which can sometimes damage them. A voltage sag occurs when the RMS voltage value decreases for a limited time before it settles and returns to its normal value. Voltage sag is generally caused by a short circuit fault or by a sudden change in the characteristics of a power source or a load requiring high current to start. If the voltage sag is severe, some equipment may not be able to function.

A typical voltage sag is a sudden reduction in the supply voltage to a value between 90% and 1% of the declared voltage, followed by a voltage recovery after a short period of time. Conventionally the duration of a voltage dip is between 10 milliseconds and 1 minute. The depth of a voltage dip is defined as the difference between the minimum RMS voltage during the voltage dip and the declared voltage. Voltage changes which do not reduce the supply voltage to less than 90% of the declared voltage are not considered to be sags. Figures given below shows recorded voltage sags at Pune bus depot.

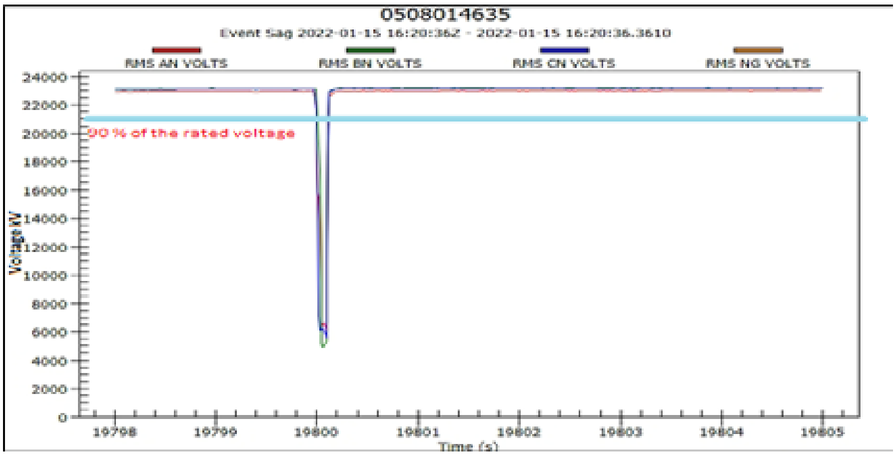


Figure 2-8: Voltage sag at Pune bus depot - 22% Unom (Nominal Voltage)

In the above figure, the voltage dips from the rated voltage of 22 kV to 4.84 kV (22% of rated voltage). The threshold value for the voltage sag is 90% of the rated voltage of 22 kV which is 19.8 kV. This occurred on 15 January 2022 at 20:36 hrs.

Table 2-1: List of sags less than 60% of Unom recorded at Pune

Sl No	Date	Duration (sec)	Voltage (Volt)	% of Unom	Direction
1	03-08-2021	0.10000	10690.00	46.88	Upstream
2	03-08-2021	0.09099	10850.00	47.63	Upstream
3	14-08-2021	0.11100	3441.00	15.27	Upstream
4	01-09-2021	0.08998	7711.00	33.88	Upstream
5	06-10-2021	0.09102	12200.00	53.40	Upstream
6	06-10-2021	0.09995	12370.00	54.06	Upstream
7	08-10-2022	0.11999	10380.00	45.69	Upstream
8	28-02-2022	0.07998	13670.00	60.00	Upstream
9	01-03-2022	0.08002	10120.00	44.00	Upstream
10	11-03-2022	0.08003	7280.00	31.00	Upstream
11	09-04-2022	0.1400	4765.00	22.00	Upstream
12	09-04-2022	0.1300	10140.00	47.00	Upstream
13	13-04-2022	0.1300	12780.00	58.00	Upstream
14	16-04-2022	0.09102	9624.00	45.00	Upstream
15	27-04-2022	0.08999	11170.00	52.00	Upstream
16	27-04-2022	0.1110	11660.00	52.00	Upstream
17	27-04-2022	0.1200	9405.00	41.00	Upstream
18	01-05-2022	0.08098	9408.00	41.00	Upstream
19	20-05-2022	0.08000	13030.00	56.00	Upstream
20	25-05-2022	0.1010	8999.00	42.00	Upstream
21	02-06-2022	0.03998	12850.00	56.00	Upstream
22	13-06-2022	716	2858.00	13.00	Upstream
23	13-06-2022	0.09996	7933.00	35.00	Upstream
24	15-06-2022	0.09999	9281.00	43.00	Upstream
25	16-06-2022	0.1000	6323.00	30.00	Upstream

26	19-06-2022	0.09001	13110.00	60.00	Upstream
27	20-06-2022	0.09998	6487.00	29.00	Upstream
28	22-06-2022	0.2300	9760.00	44.00	Upstream
29	23-06-2022	0.09000	4092.00	18.00	Upstream
30	23-06-2022	0.04003	1808.00	8.00	Upstream
31	23-06-2022	0.05003	13320.00	59.00	Upstream
32	24-06-2022	0.1000	7049.00	32.00	Upstream
33	24-06-2022	0.1100	11380.00	51.00	Upstream
34	24-06-2022	0.1000	11270.00	51.00	Upstream
35	29-06-2022	0.1000	13290.00	59.00	Upstream
36	06-07-2022	0.1200	12060.00	55.00	Upstream
37	11-07-2022	0.09997	6981.00	30.00	Upstream
38	11-07-2022	0.1100	11240.00	52.00	Upstream
39	11-07-2022	0.1010	9103.00	41.00	Upstream
40	12-07-2022	0.09999	3252.00	14.00	Upstream
41	13-07-2022	0.1200	11170.00	52.00	Upstream
42	14-07-2022	0.1100	8834.00	41.00	Upstream
43	15-07-2022	0.09997	11330.00	53.00	Upstream
44	17-07-2022	0.1200	3678.00	17.00	Upstream
45	17-07-2022	0.09999	7312.00	33.00	Upstream
46	20-07-2022	0.07996	9956.00	46.00	Upstream
47	21-07-2022	0.2800	8982.00	41.00	Upstream
48	24-07-2022	0.1100	11330.00	51.00	Upstream
49	24-07-2022	0.1300	9385.00	42.00	Upstream
50	24-07-2022	0.1201	7986.00	35.00	Upstream
51	24-07-2022	0.1200	7973.00	36.00	Upstream
52	30-07-2022	0.07998	10670.00	48.00	Upstream
53	30-07-2022	0.07999	10010.00	45.00	Upstream
54	31-07-2022	0.09999	13310.00	60.00	Upstream
55	03-08-2022	0.08000	10080.00	47.00	Upstream
56	06-08-2022	0.1110	4562.00	21.00	Upstream
57	07-08-2022	0.09001	12100.00	54.00	Upstream
58	07-08-2022	0.09002	11820.00	53.00	Upstream
59	07-08-2022	0.08003	8440.00	37.00	Upstream
60	08-08-2022	0.1000	9175.00	41.00	Upstream
61	08-08-2022	0.1200	7818.00	35.00	Upstream
62	09-08-2022	0.1200	12870.00	56.00	Upstream
63	09-08-2022	0.09099	8448.00	38.00	Upstream
64	09-08-2022	0.1300	12290.00	57.00	Upstream

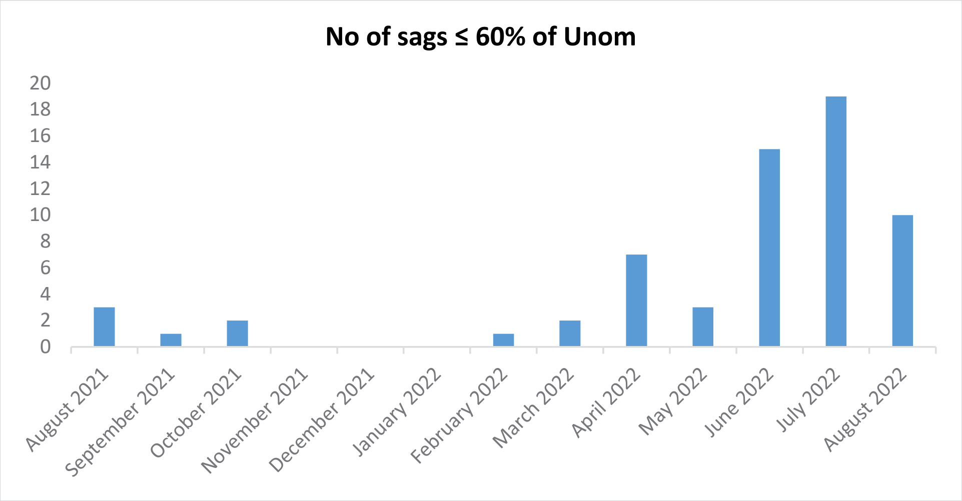


Figure 2-9: Total voltage sags

The above figure shows the voltage sags to 60% or less from August 2021 to August 2022. For the month of November 2021, December 2021 and January 2022, no sag ≤ 60% were recorded.

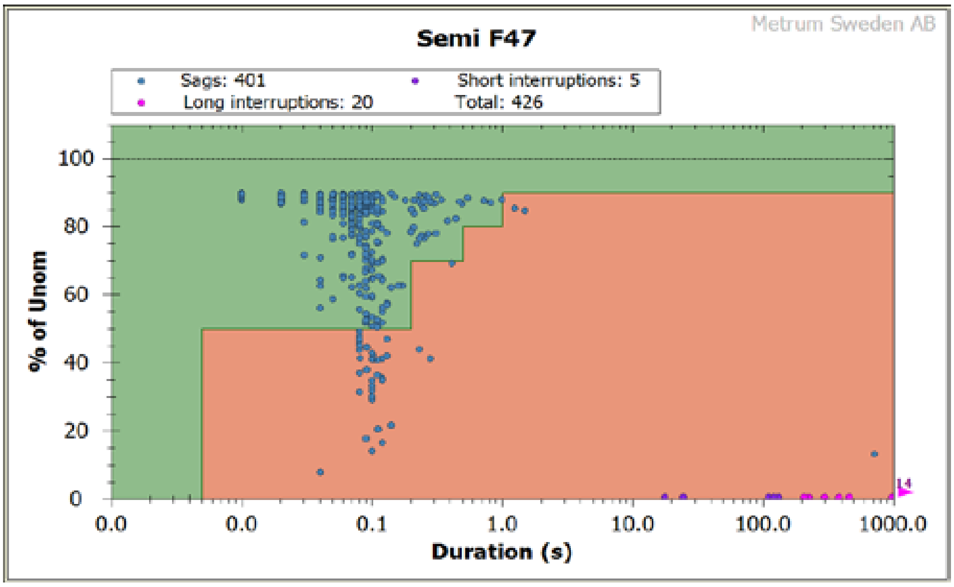
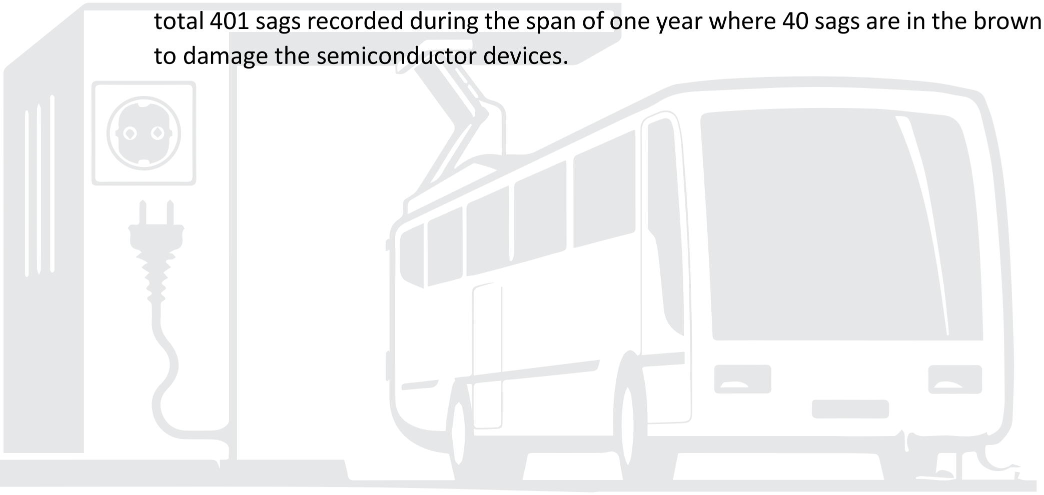


Figure 2-10: Recorded voltage sags at Pune bus depot as per Semi F47

Semi F47 is semiconductor processing equipment voltage sag immunity standard which explains the severity of voltage sags with respect to its effect on semiconductor devices. The above figure depicts the total 401 sags recorded during the span of one year where 40 sags are in the brown area having potential to damage the semiconductor devices.



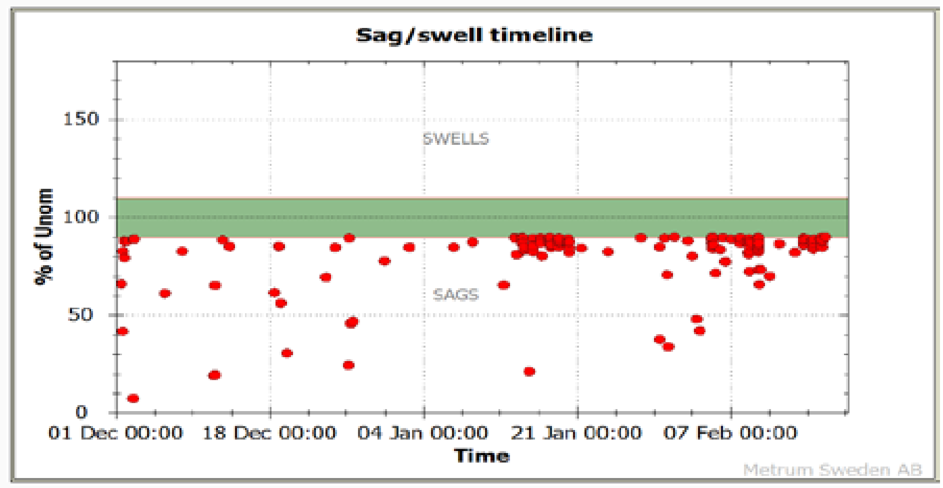


Figure 2-11: Voltage sags recorded

Above figure depicts all the events of sags recorded for the duration, no swells were recorded during the period of study. The recorded sags have originated from the transmission grid. Voltage sags could occur due to short circuits in HV grids, MV grids and LV grids.

2.4.2 Transients

Transients are power quality disturbances that involve destructive high magnitudes of current and voltage or both. It could reach thousands of volts and amps even in low voltage systems. However, such phenomena occur only for very short durations of 50 nanoseconds to maximum 50 milliseconds. Transients in power system can result in various disorder to working equipment. There is no definition of a voltage or current transient from a power quality perspective in the same way as there is definition for voltage dips, swells and interruptions and other PQ phenomena. There is no consistency in the way in which characteristics of transient voltage and currents are calculated. In EN-50160, there are still no regulations for the amplitude or number of transients which are acceptable. The voltage transients recorded at Pune bus depot are presented in Appendix V. Few severe transient recorded are presented in waveforms below.

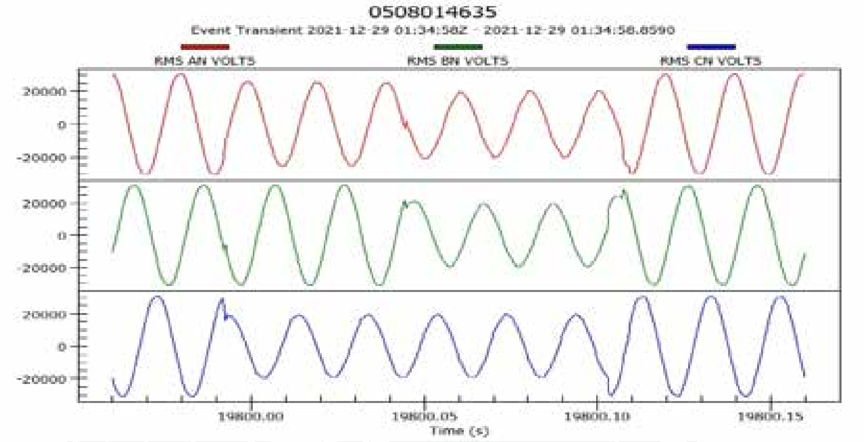


Figure 2-12: Transient recorded for 1.38 msec

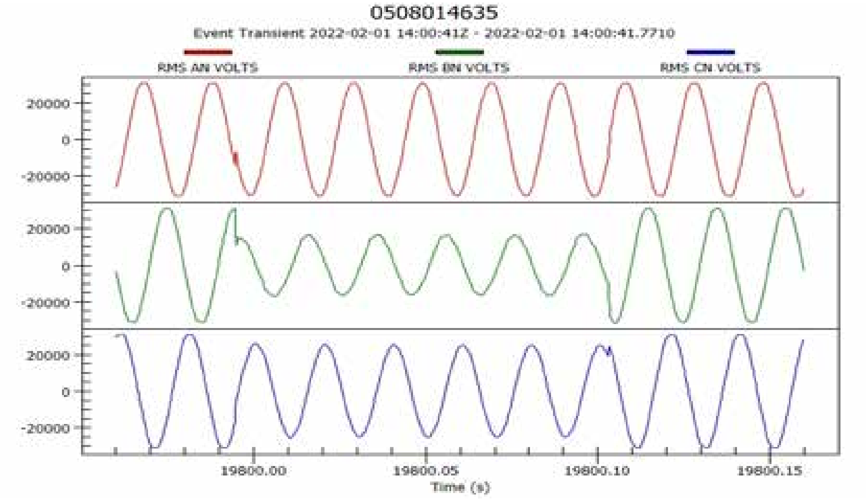


Figure 2-13: Transients recorded for 3.025 msec

Summary of the voltage transients and duration recorded at Pune from September 2021 to July 2022 is plotted below.

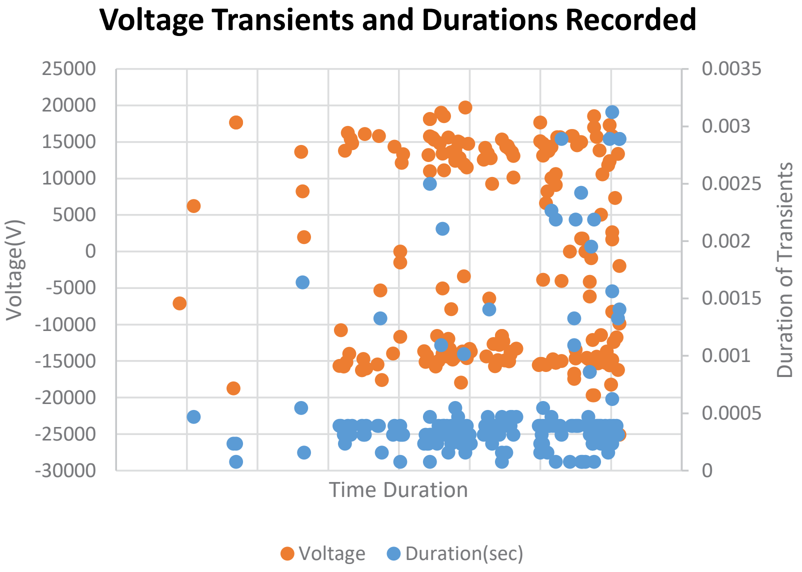


Figure 2-14: Transients recorded from September 2021 to July 2022

2.4.3 Interruption

Interruptions in an electrical network can be planned or unplanned outages. These are also referred as announced interruptions and unannounced interruptions. Announced interruptions are when an electricity user is notified prior to the interruption takes place, so that utility can perform planned maintenance work. Unannounced interruptions are caused by equipment faults. There can be long interruptions when the duration is more than three minutes and short interruptions when it last less than three minutes.

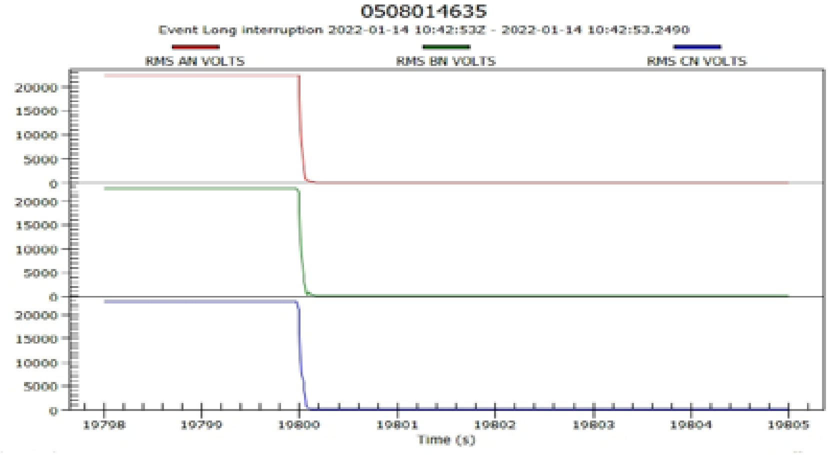


Figure 2-15: Long interruption recorded for 3 min 15 sec

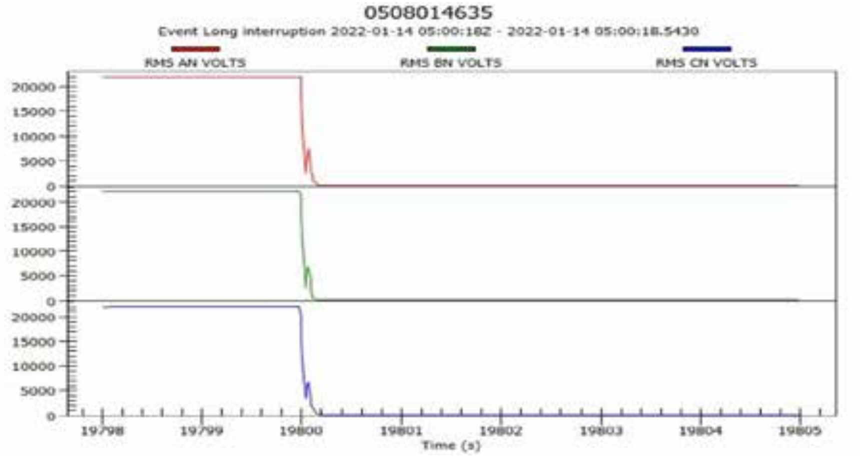


Figure 2-16: Long interruption recorded for 3 min 52 sec

Table 2-2: Long interruption events recorded at Pune

Sl No	Date	Time	Phase	Duration (milli sec)
1	14-01-2022	07:54:59	3	193
2	09-02-2022	06:54:42	3	11550
3	02-03-2022	05:59:25	3	4484
4	12-04-2022	09:46:39	2	1753
5	20-05-2022	12:49:34	2	1349
6	23-05-2022	06:49:40	2	382
7	09-06-2022	02:50:00	3	1519
8	09-06-2022	03:59:26	1	2681
9	24-06-2022	07:40:01	3	19670
10	26-06-2022	10:36:13	2	2789
11	28-06-2022	03:56:35	3	225
12	29-06-2022	12:00:07	3	1529
13	29-06-2022	10:58:42	2	459
14	04-07-2022	12:18:36	1	2186
15	07-07-2022	12:27:01	3	206
16	09-07-2022	10:40:08	3	1697

17	13-07-2022	12:31:52	3	1106
18	14-07-2022	01:00:53	3	1105
19	20-07-2022	01:00:41	3	978
20	22-07-2022	09:44:04	1	298
21	26-07-2022	12:52:35	3	2985
22	06-08-2022	07:32:27	2	5478

These interruptions may be corelated with utility data of faults and trippings.

2.4.4 Flicker

In electrical engineering, flicker is defined as short-term voltage fluctuations in the power supply system. This can cause lamps to flicker, as the brightness is proportional to the applied voltage. Many technical devices are sensitive to voltage fluctuations. High power loads such as large motor drives and arc furnaces that draw fluctuating current and cause low frequency cyclic voltage variations that result in flickers in electrical devices and electronic circuits. Flickering of light sources can cause significant physiological discomfort, physical and psychological tiredness, and even pathological effects on human beings.

Flicker Severity: Intensity of flicker annoyance defined by the UIE-IEC flicker measuring method and evaluated by the following formula:

$$P_{lt} = \sqrt[3]{\sum_{i=1}^{12} \frac{P_{sti}^{3}}{12}}$$

P_{st} - Short term severity measured over a period of ten minutes

P_{lt} - Long term severity calculated from a sequence of 12 P_{st} values over a two-hour interval

As per EN 50160 allowable limit is 1

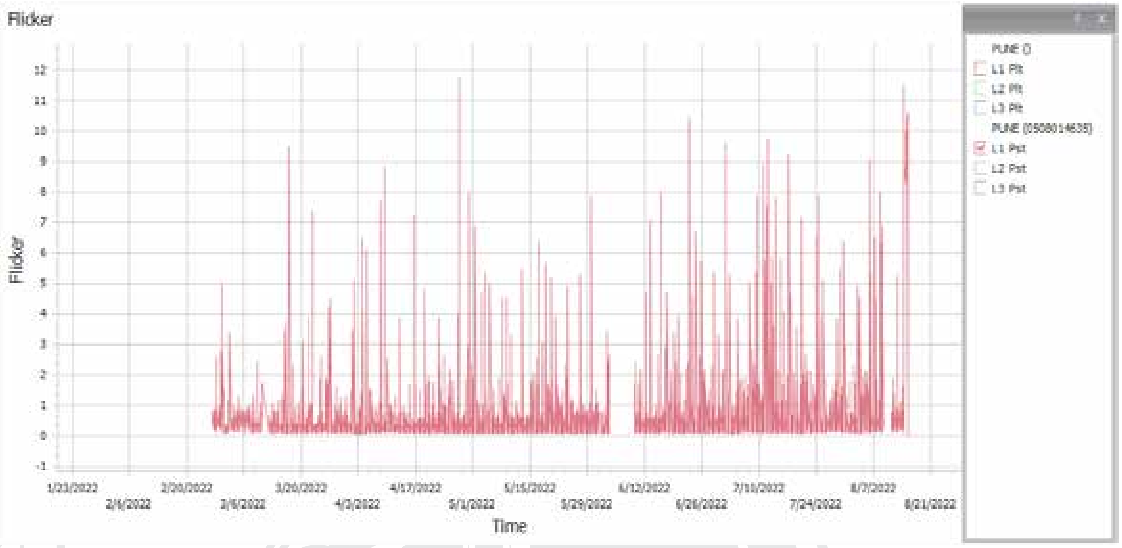


Figure 2-17: Flicker Pst (L1)

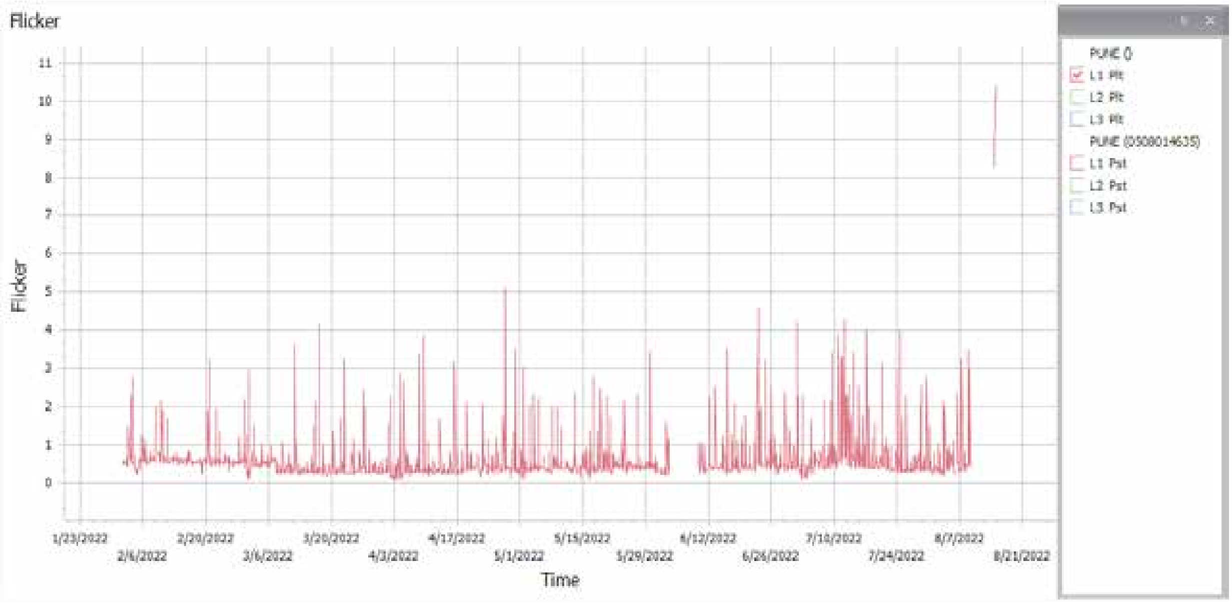


Figure 2-18: Flicker Plt (L1)

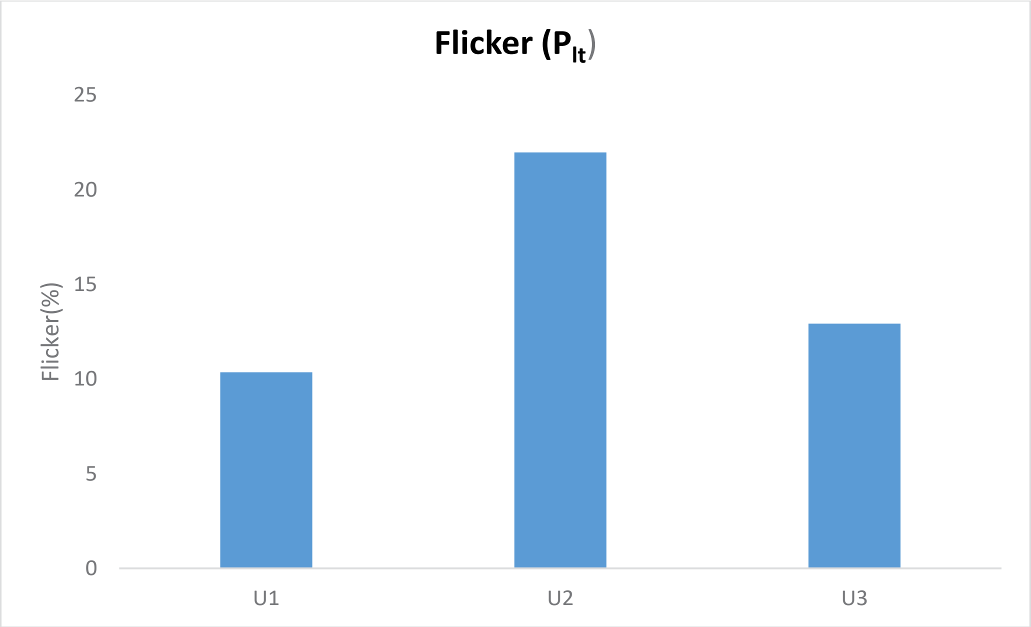


Figure 2-19: Flicker (P_{lt}) recorded for 1 year duration

The flicker recorded at Pune are within the limits (1pu) set by EN-50160.

2.4.5 Voltage

The below figure depicts recorded voltage (RMS values) at Pune bus depot, which is sampled at every minute.

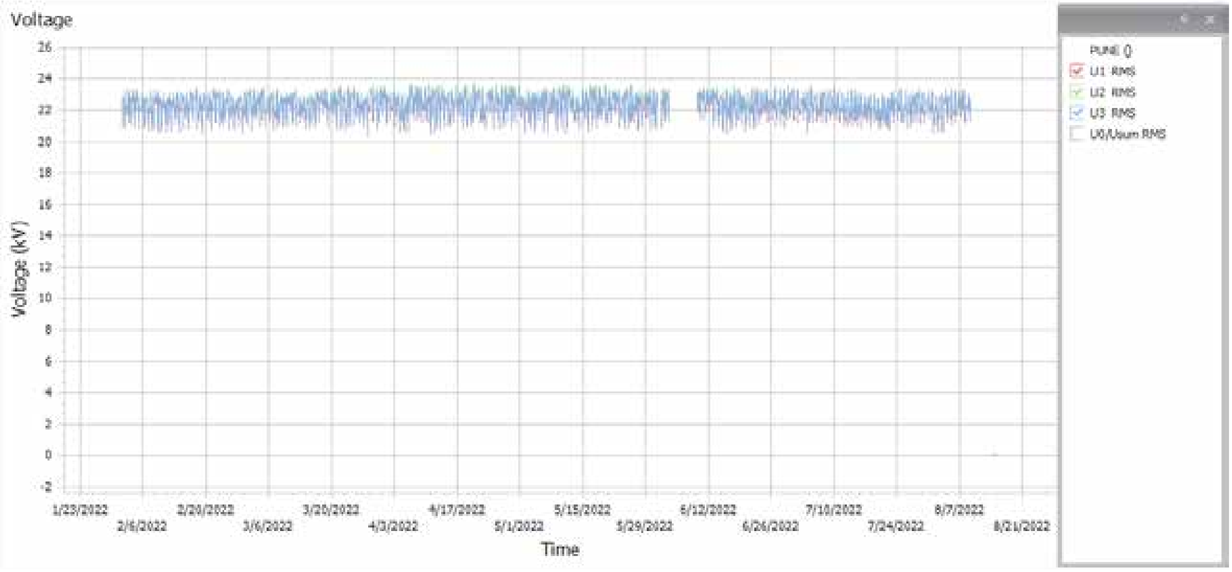


Figure 2-20: Voltage recoded at Pune bus depot

2.4.6 Current

The figure depicts the current (RMS values) recorded at Pune bus depot, which is sampled at every minute.

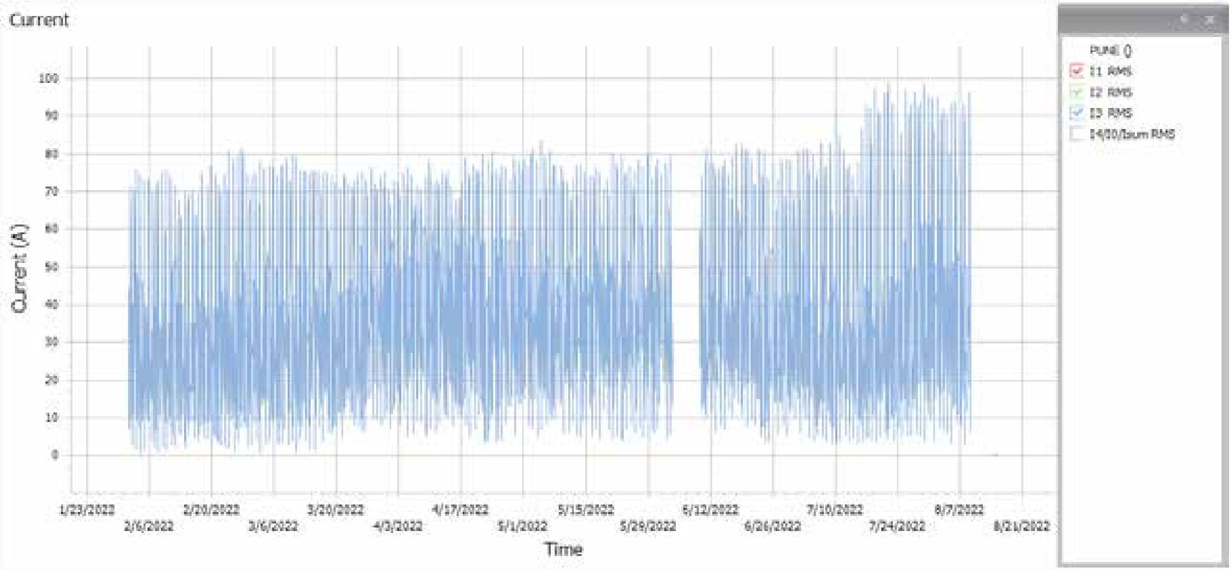


Figure 2-21: Current recorded at Pune bus depot

2.4.7 Harmonics

Harmonics in power systems are generated by non-linear loads. Semiconductor devices like transistors, IGBTs, MOSFETS, diodes etc. are all non-linear loads. Electric motors do not normally contribute significantly to harmonic generation. Both motors and transformers will however create harmonics when they are over-fluxed or saturated. When a non-linear load, such as a rectifier is connected to the system, it draws a current that is not necessarily sinusoidal. The current waveform distortion can be quite complex, depending on the type of load and its interaction with other components of the system. The presence of harmonics in the electricity distribution grid is an increasing concern. With increasing EV penetration, the situation is likely to create serious impact on the grid as EV chargers convert the AC power to DC power needed for EV batteries. The conversion of AC into DC injects harmonics in the grid which need to be monitored and controlled. In power systems, harmonics are indicated as positive integer multiples of the fundamental frequency. Thus, the third harmonic is the third multiple of the fundamental frequency (50 Hz) which is 3x50 = 150 Hz.

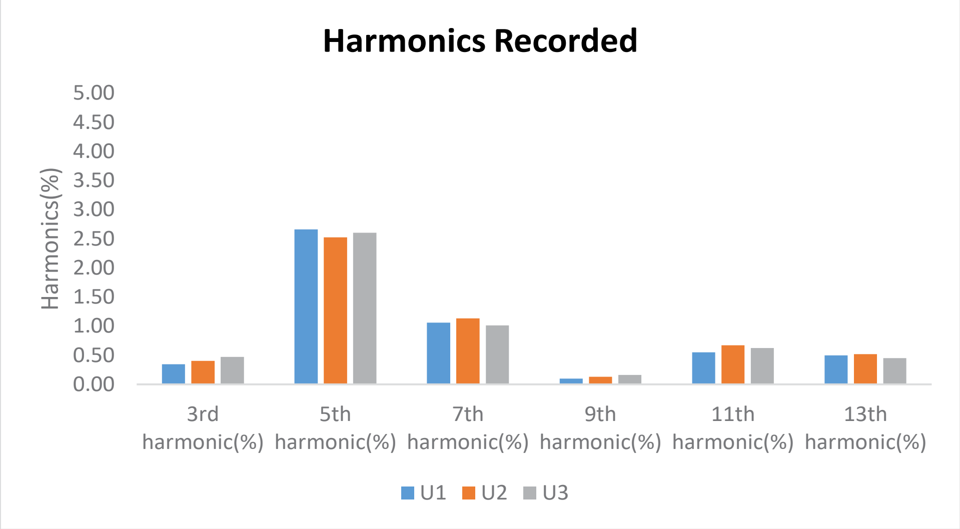


Figure 2-22: Harmonics recorded at Pune bus depot

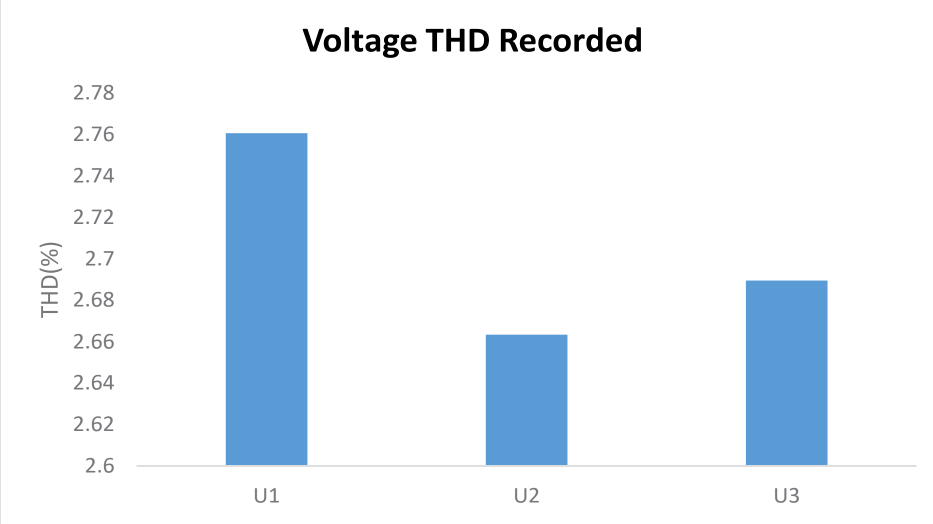


Figure 2-23: Voltage THD recorded

The voltage total harmonics distortion (THD) recorded are as per the limits (8%) set by EN-50160.

2.4.8 Voltage Variations

Voltage variations is an increase or decrease of voltage, due to variation of the total load of the distribution system or a part of it. As per EN-50160, voltage variations limit is average 10 minutes RMS values ±10% for 95% of time in a week.

In a week (24x7 = 168 hrs), 95% of 168 hrs which gives 159.6 hours. If the voltage variations are within ±10% of RMS values of nominal voltage for 159.6 hours in a week, that is acceptable as per EN-50160 standard. The voltage variations recorded at Pune bus depot during study period are within the limits ±10% as per EN-50160.

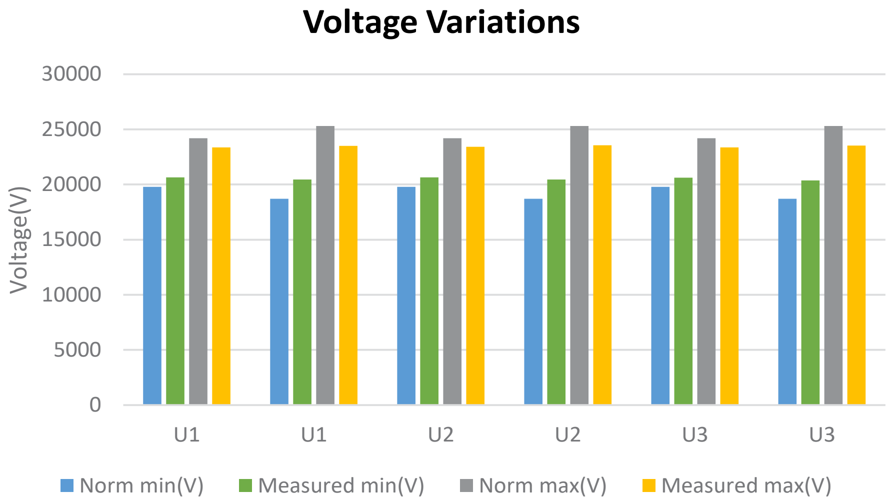


Figure 2-24: Voltage variations recorded from August 2021 to August 2022

2.4.9 Conclusion

The power quality monitoring study conducted at **PMPML Pune**, for a time span of **1st August 2021 to 9th August 2022** concludes:

- The power quality standard EN50160 is used for the PQ study and analysis
- The measured **Voltage Variations** for the complete span of time (01 August 2021 to 09 August 2022) are within the limits prescribed in EN50160
- The measured **THD** and **Individual Harmonics** for the complete span of time are within the limits prescribed in EN50160
- The measured **Voltage Imbalance** for the complete span of time are within the limits prescribed in EN50160
- The measured **Frequency and Signalling Voltage** for the complete span of time are within the limits prescribed in EN50160
- The measured **Flicker (P_{lt})** for the complete span of time are within the limits prescribed in EN50160
- The observed **Voltage Sags** for complete span of time are within the limits according to EN50160; however, during the one year of measurement, a total of 65 sags out of recorded 401 are below 60% of rated voltage. As per Semi F47, these sags have higher severity level and have the potential to damage electronic and semiconductor devices. These voltage sags were induced in the electrical networks from upstream, which need investigation. It is recommended to install class A online power quality monitoring system to continuously monitor voltage sags so that correlation can be established in case of equipment/component failure occurs. It is recommended to have continuous online monitoring system and perform regular analysis for a longer period of time till the installed load increase to the planned load (maximum).

- The load profile observed at the PQ measurement point is less than 50% of the total capacity, **however if the loading increases the power quality may degrade**

2.5 Load Flow Study on the 22 kV Feeder and EVSE Network

The detailed impact study of the 22 kV feeder for PMPML Bhekrainagar bus depot, Pune has been performed using CYME power system simulation software. The CYME power system analysis software is a comprehensive suite of advanced simulation tools to help power engineers address daily and emerging challenges in power network planning and operation. The CYME software provides powerful modelling capabilities that support the detailed modelling of any distribution, industrial or transmission network. It supports the creation of balanced and unbalanced networks, secondary grids, substations, low-voltage distribution systems, DC systems and nested networks. These networks can be radial or meshed, and can be represented both geographically and schematically. The software provides a wide spectrum of analysis to allow different simulations. The program offers basic analysis such as power flow short-circuit, load allocation, capacitor placement, load balancing and motor starting. Advanced analysis modules include contingency analysis, arc flash hazards, long-term dynamics, volt/var optimization, protective device coordination, transient stability, harmonics, and many more.

The unbalanced three-phase load flow simulation and harmonic analysis have been conducted to study the system performance for the impact of EVSE on the conventional electrical network. The combinations of both AC and DC chargers have been connected at the selected feeder to study the impact. Total 58 AC chargers of 80 kW capacity (with 2 guns of 40 kW each) and 5 DC chargers (2 x 150 kW and 3 x 180 kW) are installed at Bhekrainagar bus depot, Pune. AC chargers provide charging at constant power level while the DC chargers have been modelled as an individual component followed by the DC load (EV). DC charger is a constant voltage source, maintaining its terminal bus voltage at the desired control value as specified in the network settings.

2.5.1 Load Flow Study Scenarios

The objective of the modelling study is to analyze the impact of EV charging load on the grid. Below are the inputs considered to model the 22 kV Poonawala Feeder at Phursungi substation. There are 5 packaged sub-stations (PSS) which supply LT power to the AC and DC chargers.

Table 2-3: List of PSS installed at Pune bus depot

Network Id	Equipment No	Equipment Id	Status	Phase	Cap Nom (kVA)	Prim Volt (kV$_{LL}$)	Sec Volt (kV$_{LL}$)	No load loss (kW)
PSS -1	PSS_1_TFR	1250KVA_22/0.433KV	Connected	ABC	1250.00	22.00	0.43	1.60
PSS -2	PSS_2_TFR	1250KVA_22/0.433KV	Connected	ABC	1250.00	22.00	0.43	1.60
PSS -3	PSS_3_TFR	1250KVA_22/0.433KV	Connected	ABC	1250.00	22.00	0.43	1.60
PSS -4	PSS_4_TFR	1250KVA_22/0.433KV	Connected	ABC	1250.00	22.00	0.43	1.60
PSS -5	PSS_5_TFR	1250KVA_22/0.433KV	Connected	ABC	1250.00	22.00	0.43	1.60

Table 2-4: List of chargers installed at Pune bus depot

Feeder Id	Chargers Type	Rated Power (kW)	Input Voltage (kV_{LL})	Output Voltage (V)	Efficiency (%)	Operating Voltage (V)	Operating PF (%)
PSS-1 AC CHARGERS - 1 to 13	AC CHARGERS_80 kW	80	0.4			Fixed Voltage	95
PSS-2 AC CHARGERS - 14 to 26	AC CHARGERS_80 kW	80	0.4			Fixed Voltage	95
PSS-2 DC CHARGERS -1	DC CHARGERS_150 kW	150	0.4	750.0	90.0	750	95
PSS-3 AC CHARGERS -27 to 39	AC CHARGERS_80 kW	80	0.4			Fixed Voltage	95
PSS-3 DC CHARGERS-2	DC CHARGERS_180 kW	180	0.4	750.0	90.0	750	95
PSS-4 AC CHARGERS -40 to 51	AC CHARGERS_80 kW	80	0.4			Fixed Voltage	95
PSS-4 DC CHARGERS-3	DC CHARGERS_150 kW	150	0.4	750.0	90.0	750	95
PSS-5 AC CHARGERS -52 to 58	AC CHARGERS_80 kW	80	0.4			Fixed Voltage	95
PSS-5 DC CHARGERS-4	DC CHARGERS_180 kW	180	0.4	750.0	90.0	750	95
PSS-5 DC CHARGERS-5	DC CHARGERS_180 kW	180	0.4	750.0	90.0	750	95

The following are the assumptions and considerations taken for the simulation model:

- The output DC voltage of 150 kW and 180 kW DC chargers has been taken as 750 V
- The efficiencies of 150 kW DC Chargers and 180 kW DC chargers have been assumed to be 95%
- The power factor for the selected feeder has been assumed to be 95%
- The harmonic injections spectrum for EVSE has been assumed to be same as that of the harmonics measured at EVSE at PMPML Bus Depot, Pune

The system studies have been performed for following cases:

Table 2-5: Different scenarios considered for load flow study

Sl No	Case No	Case Status	Year	Load Growth (%) Per Year	Total EVSE Load (kW)
1	Case 1	As-Is	2022	0	5480
2	Case 2	As-Is (As per PQM Readings)	2022	0	3819
3	case 3	2 Year load growth + Additional EVSEs	2024	6	8233
4	case 4	5 Year load growth + Additional EVSEs	2027	6	12301

- **Case 1:** For As- Is scenario, all EVSEs are connected to perform load flow and harmonic analysis.
- **Case 2:** For As-Is (as per recorded data of PQM) scenario, real time recorded data by Power Quality Meter is considered to perform load flow and harmonic analysis.
- **Case 3**: For 2024 scenario, 6% of load growth per year applied on As-Is network to perform load flow and harmonic analysis with newly added AC and DC chargers.
- **Case 4**: For 2027 scenario, 6% of load growth per year applied on As-Is network to perform load flow and harmonic analysis with newly added AC and DC chargers.

Table 2-6: Summary of load flow study of different scenario

Parameter	Case 1: 2022 (With EVSE)	Case 2: 2022 as per PQM data (With EVSE)	Case 3: 2024 (With EVSE)	Case 4: 2027 (With EVSE)
Total Source Dispatch (kW)	5633.26	4131.098	8504.84	12678.667
Total Load (kW) (including EVSE-AC Load & 6 % Increment/year)	5479.78	3849.98	8233.60	12301.46
Total Source (kVA)	5732.43	3940.15	8691.51	12769.173
Total Loss (kW)	153.59	71.40	261.69	377.21
Total EVSE Load (kW)	5480.00	330.00	1500.00	2190.00
Total Source (kVAR)	1061.66	384.21	1836.43	1517.63
Total Loss (kVAR)	1089.44	412.25	1866.50	1564.41
No. of Overloaded Elements	4	0	15	26
No. of Under-Voltage Sections	0	0	0	0

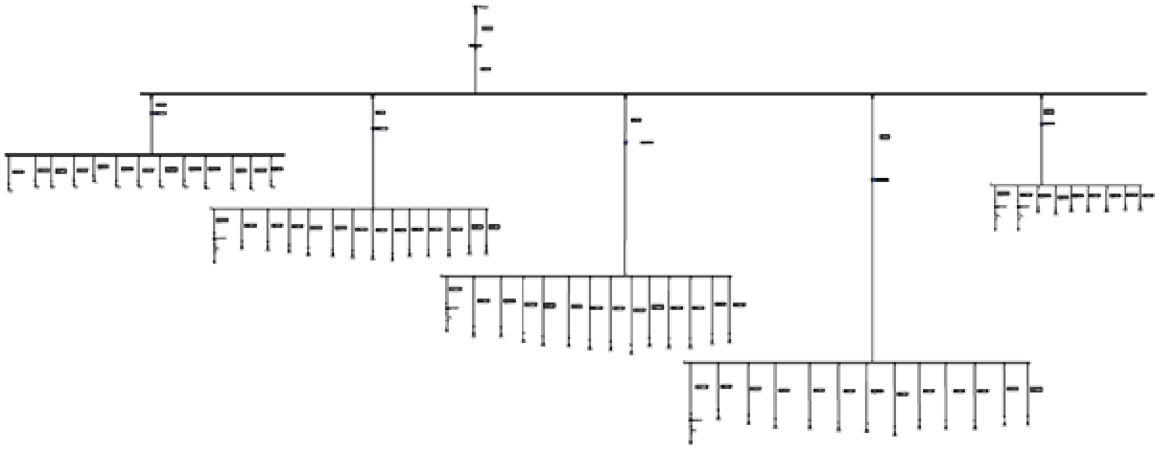


Figure 2-25: Installed chargers at Pune bus depot – 2022 scenario

2.5.2 Power Flow and Harmonic Analysis

Power flow analysis is carried out for different cases on the existing network to identify the abnormal conditions if any, such as over loading of the distribution network etc. The objective of a load flow is the analysis of the steady state performance of the power system under various operating conditions. The load flow analysis of a radial distribution feeder requires an iterative technique that is specifically designed and optimized for radial or weakly meshed systems. The voltage drop analysis method includes a full three phase unbalanced algorithm that computes phase voltages (V_A, V_B and V_C), power flows and currents including the neutral current.

Harmonic analysis is carried out for different cases on the existing network and EVSE evaluating the impact of EVSE on the electrical network with respect to IEEE 519-2014. Integration of EVSE may have adverse effect on the distribution network if the implementation is not carefully and systematically planned due to the nonlinear nature of EVSE load that generate harmonics which can cause abnormal operation such as increased losses, reduced efficiency, temperature rise, and premature insulation and winding failures. As per IEEE 519-2014, the voltage and current distortion limits for different voltage are shown in the table below. In addition, IEEE 519-2014 allows the harmonic distortions to exceed up to maximum of 150% of the specified limits for short periods and such harmonic distortions are acceptable as per IEEE standard.

Table 2-7: Harmonic voltage distortion limits according to IEEE 519

Bus Voltage at Point of Common Connection (PCC)	Individual Voltage Distortion - IDD (%)	Total Voltage (Harmonic) Distortion - THD (%)
1.0 kV and below	5	8
Above 1.0 kV through 69 kV	3	5
Above 69 kV through 161 kV	1.5	2.5
Above 161 kV	1	1.5

Table 2-8: Harmonic current distortion limits according to IEEE 519

Maximum harmonic current distortion in percentage of I_L						
Individual harmonic order (odd harmonics)						
I_{SC}/I_L	3≤h<11	11≤h<17	17≤h<23	23≤h<35	35≤h<50	TDD
<20	4	2	1.5	0.6	0.3	5
20<50	7	3.5	2.5	1	0.5	8
50<100	10	4.5	4	1.5	0.7	12
100<1000	12	5.5	5	2	1	15
>1000	15	7	6	2.5	14	20
Even harmonics distortions are limited to 25% of the odd harmonic limits						
IL=Maximum demand load current (fundamental frequency component) at PCC						
ISC=Maximum short circuit current at PCC (Point of Common Connection)						
TDD = Total Demand Distortion						

2.5.3 Load Flow of As-Is - 2022 Scenario of Pune Bus Depot

In the As-Is scenario of 2022, there are 58 AC chargers of 80 kW capacity (with 2 guns of 40 kW each) and 5 DC chargers (2 x 150 kW and 3 of 180 kW). The Tables below depict the power flow situation with the EVSE load, and its impact on the grid. The total losses in the system estimated at 153.59 kW.

Table 2-9: Load flow summary of Pune bus depot 2022 scenario

Study Parameters	
Calculation Method	Voltage Drop - Unbalanced
Tolerance	0.01 %
Load Factors	Global (P=100.00%, Q=100.00%)
Shunt Capacitors	On
Sensitivity Load Model	From Library

Total Summary	**kW**	**kVAR**	**kVA**	**PF (%)**
Sources (Swing)	5633.26	1061.66	5732.43	98.27
Generators	0.00	0.00	0.00	0.00
Total Generation	**5633.26**	**1061.66**	**5732.43**	**98.27**
Load read (Non-adjusted)	4640.00	0.00	4640.00	100.00
Load used (Adjusted)	4639.89	-0.15	4639.89	100.00
EVSE DC load	**839.78**	**919.00**	**1317.00**	
Shunt capacitors (Adjusted)	0.00	0.00	0.00	0.00
Shunt reactors (Adjusted)	0.00	0.00	0.00	0.00
Motors	0.00	0.00	0.00	0.00
Total Loads	**5479.78**	**919.00**	**5957.00**	**100.00**
Cable Capacitance	0.00	-27.63	27.63	0.00
Line Capacitance	0.00	0.00	0.00	0.00
Total Shunt Capacitance	**0.00**	**-27.63**	**27.63**	**0.00**
Line Losses	6.26	14.58	15.87	39.43
Cable Losses	26.48	12.29	29.19	90.71
Transformer Load Losses	68.18	151.57	166.19	41.02
Transformer No-Load Losses	7.99	0.00	7.99	100.00
Total Losses	**153.59**	**1089.44**	**1100.21**	**13.96**

Annual System Losses	**kW**	**MW-h/year**
Line Losses	6.26	54.81
Cable Losses	26.48	231.97
Transformer Load Losses	68.18	597.22
Transformer No-Load Losses	7.99	69.96
Total Losses	153.59	1345.45

In this scenario, the difference between the adjusted and non-adjusted loads mentioned in the above table is very small; and hence less abnormal condition (overloaded, under voltage) present in the network, which is under tolerance limits. In this scenario, only one transformer PSS-3 TFR is overloaded; and the loading of that transformer is 101%. Overloaded transformer is shown in the below Figure.

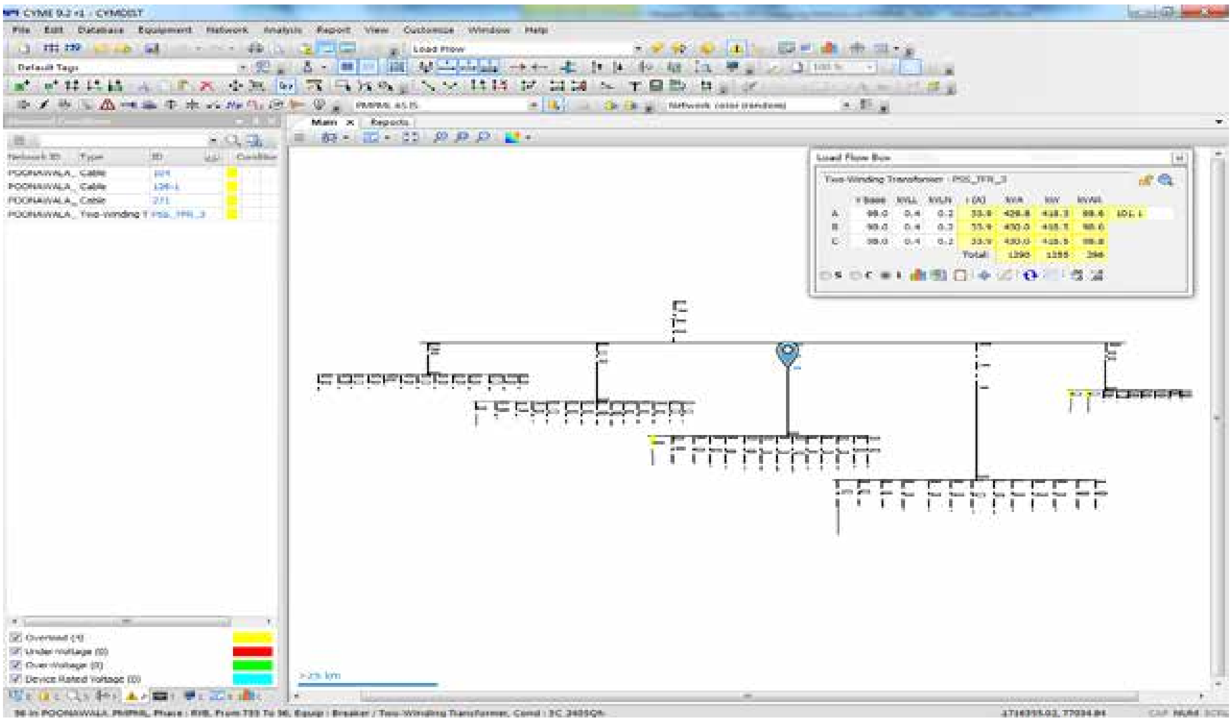


Figure 2-26: Over loaded transformer as PSS-3 in 2022 scenario

The voltage profile for 22 kV Poonawala feeder from Phursungi 132/22 kV MUSS has been plotted in the below figure. There is a problem of low voltage persisting in the feeder which drops the base voltage to 95.9 V per unit (compared to 100 V per unit) at a distance of 1151m from the feeder head approximately in the year 2022 scenario.

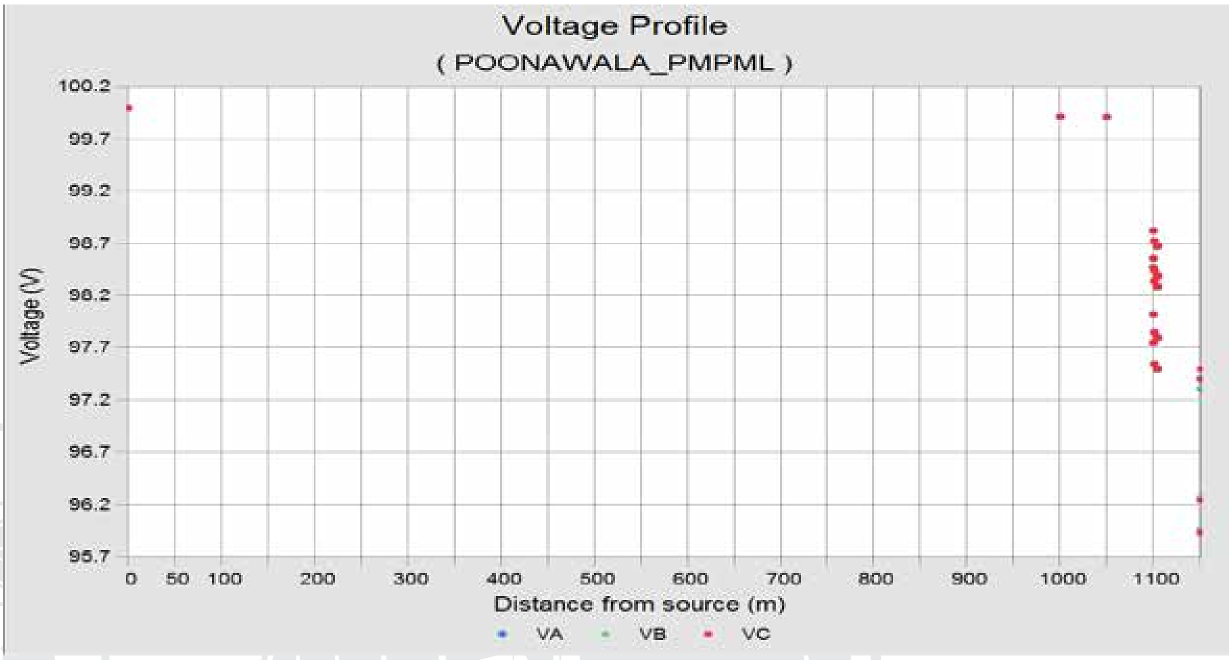


Figure 2-27: Voltage profile at Pune bus depot in 2022 scenario

2.5.4 Load Flow of As-Is - 2022 Scenario (As per Load Recorded by the PQM) of Pune Bus Depot

In this scenario, real time data recorded by the PQM is considered for load flow analysis. Below are the inputs considered which are taken from the PQM readings of 29 July 2022 with active power of 3821.79 kW where EVSE considered are 44x80 kW AC chargers, 1x150 kW DC charger and 1x180 kW DC charger to match the active power of 3821.79 kW.

Active Power (kW)	Reactive power (kVAR)	Apparent Power (kVA)
3821.7975	9.956224609	3823.904

Table 2-10: List of PSS considered for As-Is 2022 scenario (as per PMQ)

Network Id	Equipment No	Equipment Id	Cap Nom (kVA)	Prim Volt (kV$_{LL}$)	Sec Volt (kV$_{LL}$)	No load loss (kW)
PSS -1	PSS_TFR_1	1250 kVA_22/0.433 kV	1250	22	0.433	1.6
PSS -2	PSS_TFR_2	1250 kVA_22/0.433 kV	1250	22	0.433	1.6
PSS -3	PSS_TFR_3	1250 kVA_22/0.433 kV	1250	22	0.433	1.6
PSS -4	PSS_TFR_4	1250 kVA_22/0.433 kV	1250	22	0.433	1.6
PSS -5	PSS_TFR_5	1250 kVA_22/0.433 kV	1250	22	0.433	1.6

Table 2-11: List of chargers considered for As-Is 2022 scenario (as per PMQ)

Feeder Id	Chargers Type	Rated Power (kW)	Input Voltage (kV$_{LL}$)	Output Voltage (V)	Efficiency (%)	Operating Voltage (V)	Operating PF (%)
PSS-4 DC CHARGERS-3	DC – 150 kW	150	0.4	750.0	90.0	750	95
PSS-5 DC CHARGERS-4	DC – 180 kW	180	0.4	750.0	90.0	750	95
PSS-1 AC CHARGERS - 1 to 10	AC – 80 kW	80	0.4			430	95
PSS-2 AC CHARGERS - 14 to 23	AC – 80 kW	80	0.4			430	95
PSS-3 AC CHARGERS - 27 to 36	AC – 80 kW	80	0.4			430	95
PSS-4 AC CHARGERS - 40 to 48	AC – 80 kW	80	0.4			430	95
PSS-5 AC CHARGERS - 52 to 56	AC – 80 kW	80	0.4			430	95

* Chargers which are not mentioned in the above table, are not considered (as OFF) in As-Is 2022 PQM scenario.

This scenario with EVSE of 44x80 kW AC chargers, 1x150 kW DC charger and 1x180 kW DC chargers is mentioned below. The model estimates the total losses at 71.40 kW.

Table 2-12: Load flow summary of Pune bus depot of 2022 scenario (as per PQM)

Study Parameters				
Calculation Method	Voltage Drop - Unbalanced			
Tolerance	0.01 %			
Shunt Capacitors	On			
Sensitivity Load Model	From Library			
Total Summary	**kW**	**kVAR**	**kVA**	**PF (%)**
Sources (Swing)	3921.37	384.21	3940.15	99.52
Generators	0.00	0.00	0.00	0.00
Total Generation	**3921.37**	**384.21**	**3940.15**	**99.52**
Load read (Non-adjusted)	4640.00	0.00	4640.00	100.00
Load used (Adjusted)	3519.98	-0.04	3519.98	100.00
EVSE DC Load	**330.00**	**302.00**	**632.00**	
Shunt capacitors (Adjusted)	0.00	0.00	0.00	0.00
Shunt reactors (Adjusted)	0.00	0.00	0.00	0.00
Motors	0.00	0.00	0.00	0.00
Total Loads	**3819.98**	**302.00**	**4151.98**	**100.00**
Cable Capacitance	0.00	-28.01	28.01	0.00
Line Capacitance	0.00	0.00	0.00	0.00
Total Shunt Capacitance	**0.00**	**-28.01**	**28.01**	**0.00**
Line Losses	2.94	6.85	7.45	39.43
Cable Losses	10.88	4.91	11.93	91.15
Transformer Load Losses	32.03	71.20	78.07	41.02
Transformer No-Load Losses	7.99	0.00	7.99	100.00
Total Losses	**71.40**	**412.25**	**418.39**	**17.06**

Annual System Losses	kW	MW-h/year
Line Losses	2.94	25.75
Cable Losses	10.88	95.27
Transformer Load Losses	32.03	280.56
Transformer No-Load Losses	7.99	70.00
Total Losses	71.40	625.43

In this scenario, the difference between adjusted and non-adjusted loads mentioned in the above table is very small; and hence less abnormal conditions (overloaded, under voltage) present in the network, which is under tolerance limits.

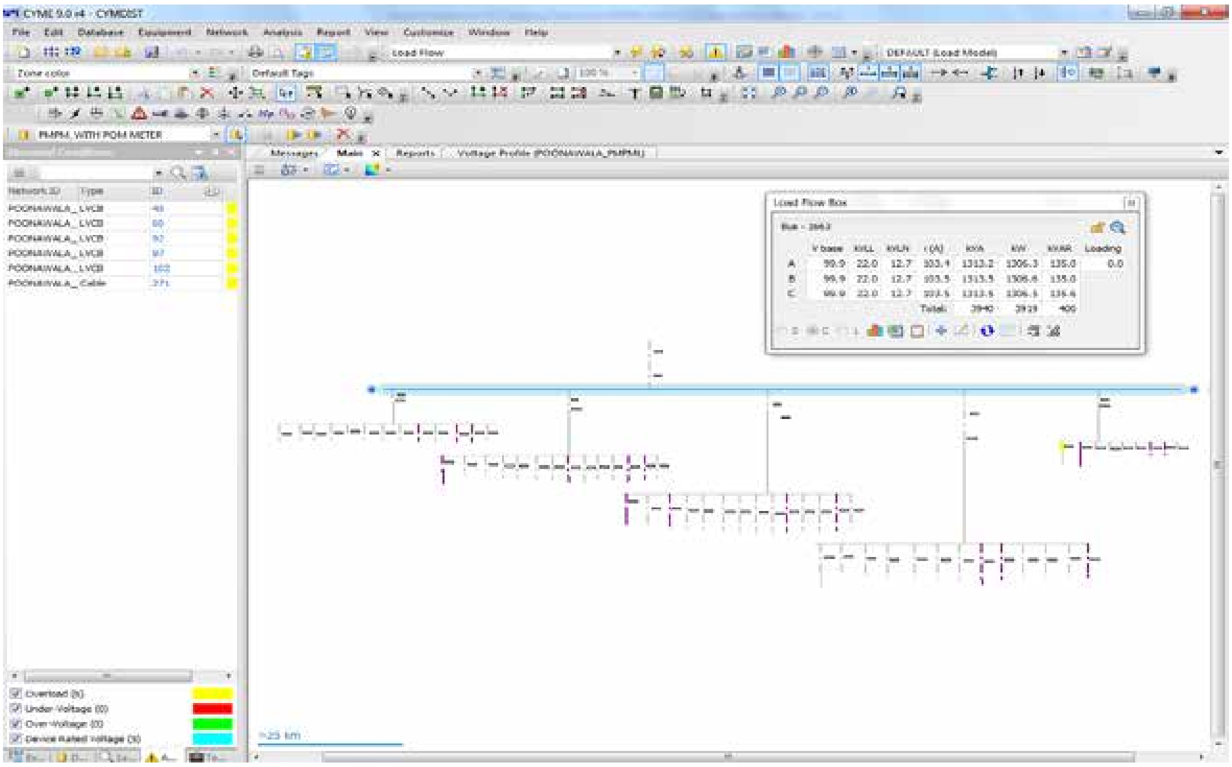


Figure 2-28: Network of As Is 2022 scenario (as per PQM)

In above figure, purple colour referred as chargers are in OFF condition.

The voltage profile for 22 kV Poonawala Feeder from Phursungi 132/22 MUSS has been plotted in the figure below. There is a problem of low voltage (in per unit) persisting in the feeder which drops the base voltage to as low as 97 V per unit (compared to 100 V per unit) at a distance of 1151m from the feeder head.

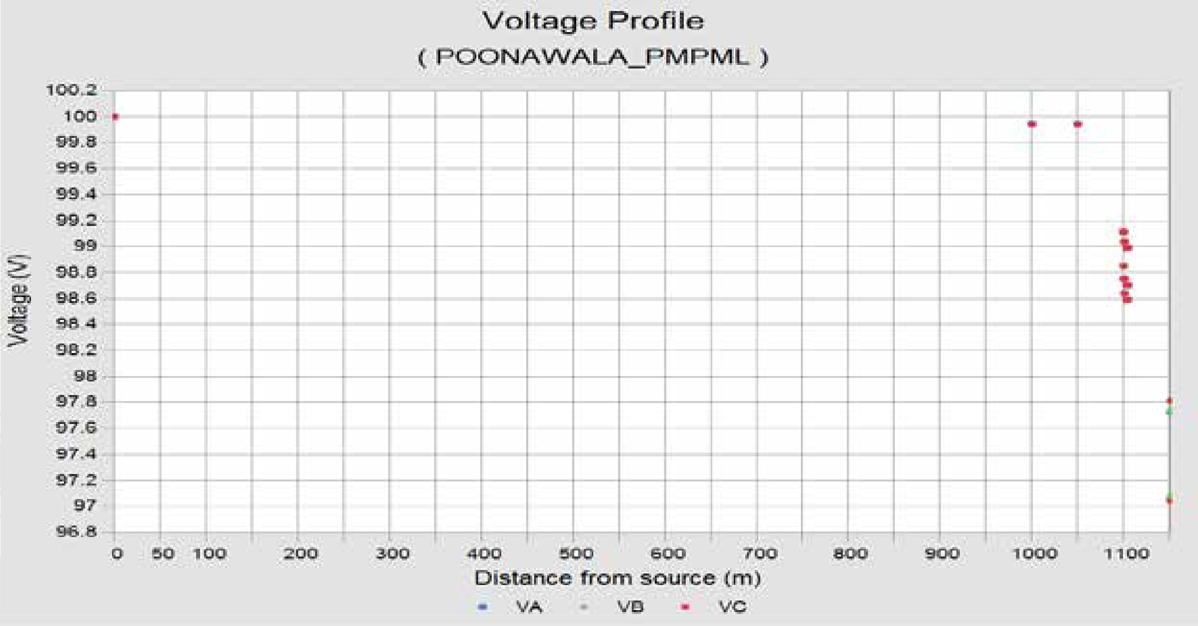


Figure 2-29: Voltage profile at Pune bus depot in 2022 scenario (as per PQM)

2.5.5 Load Flow of 2024 scenario of Pune Bus Depot

Total EVSE load of 8233.60 kW is considered for 2024 scenario, with 77x80 kW AC chargers, 4x150 kW DC chargers and 5x180 kW DC chargers. Seven number of 1250 kVA PSS are required in this scenario. The model estimates the total losses at 261.69 kW. The number of overloaded and abnormal elements have also increased.

Table 2-13: Load flow summary of Pune bus depot of 2024 scenario

Study Parameters				
Calculation Method	**Voltage Drop - Unbalanced**			
Tolerance	0.01 %			
Load Factors	Global (P=100.00%, Q=100.00%)			
Shunt Capacitors	On			
Sensitivity Load Model	From Library			
Total Summary	**kW**	**kVAR**	**kVA**	**PF (%)**
Sources (Swing)	8495.29	1836.43	8691.52	97.74
Generators	0.00	0.00	0.00	0.00
Total Generation	**8495.29**	**1836.43**	**8691.52**	**97.74**
Load read (Non-adjusted)	6733.62	0.00	6733.62	100.00
Load used (Adjusted)	6733.60	0.00	6733.60	100.00
EV DC Load	**1500.00**	**1583.00**	**2313.00**	
Shunt capacitors (Adjusted)	0.00	0.00	0.00	0.00
Shunt reactors (Adjusted)	0.00	0.00	0.00	0.00
Motors	0.00	0.00	0.00	0.00
Total Loads	**8233.60**	**1583.00**	**9046.60**	**100.00**
Cable Capacitance	0.00	-30.07	30.07	0.00
Line Capacitance	0.00	0.00	0.00	0.00
Total Shunt Capacitance	**0.00**	**-30.07**	**30.07**	**0.00**
Line Losses	10.31	24.02	26.14	39.43
Cable Losses	48.02	22.78	53.15	90.35
Transformer Load Losses	112.32	249.72	273.81	41.02
Transformer No-Load Losses	11.17	0.00	11.17	100.00
Total Losses	**261.69**	**1866.51**	**1884.76**	**13.88**

Annual System Losses	kW	MW-h/year
Line Losses	10.31	90.30
Cable Losses	48.02	420.67
Transformer Load Losses	112.32	983.95
Transformer No-Load Losses	11.17	97.85
Total Losses	261.69	2292.37

In this scenario, the difference between adjusted and non-adjusted loads mentioned in the above table is very small and hence less abnormal conditions (overloaded, under voltage) present in the network, which is with in tolerance limits. In the network, three transformers are overloaded. Loading of one of them, PSS-3 TFR is 113.3%. Overloaded transformers are shown in the figure below.

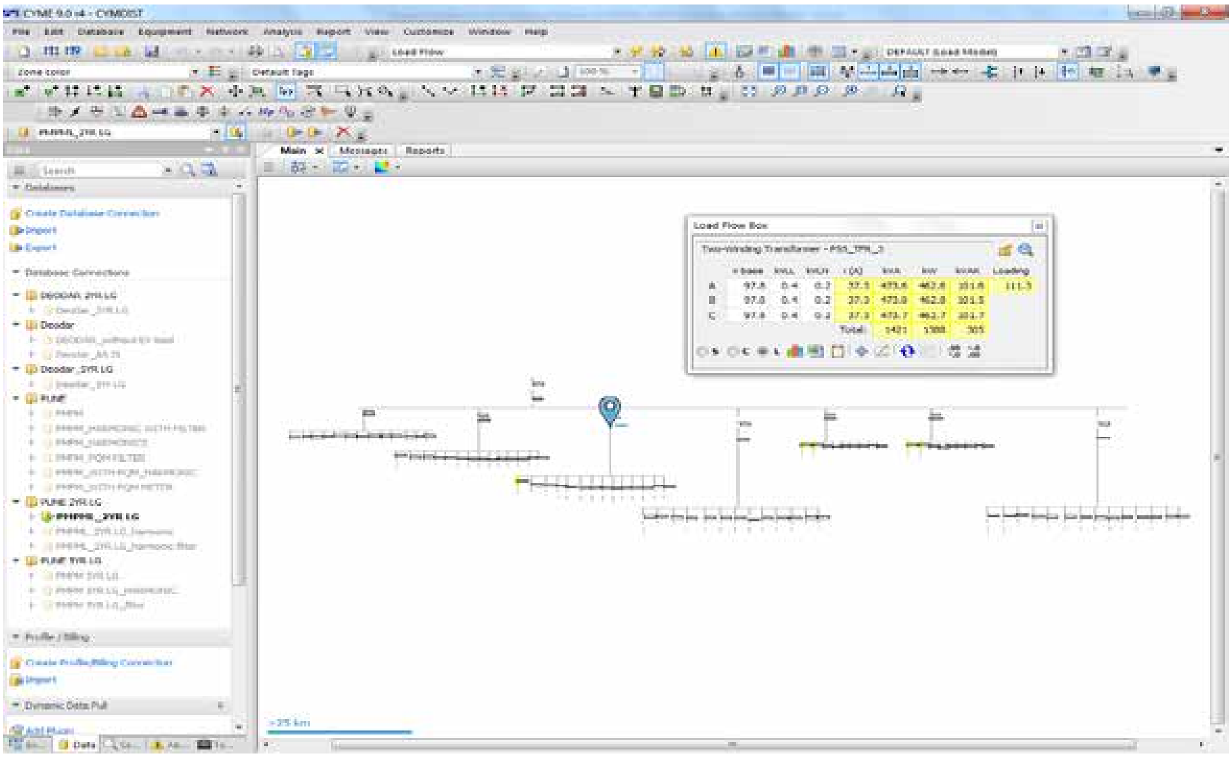


Figure 2-30: Over loaded transformer as PSS-3 in 2024 scenario

The voltage profile for 22 kV Poonawala feeder from Phursungi 132/22 MUSS has been plotted in the figure below. There is a problem of low voltage (per unit) persisting in the feeder, which drops the base voltage to 95.8 V per unit (compared to 100 V per unit) at a distance of 1151m from the feeder head.

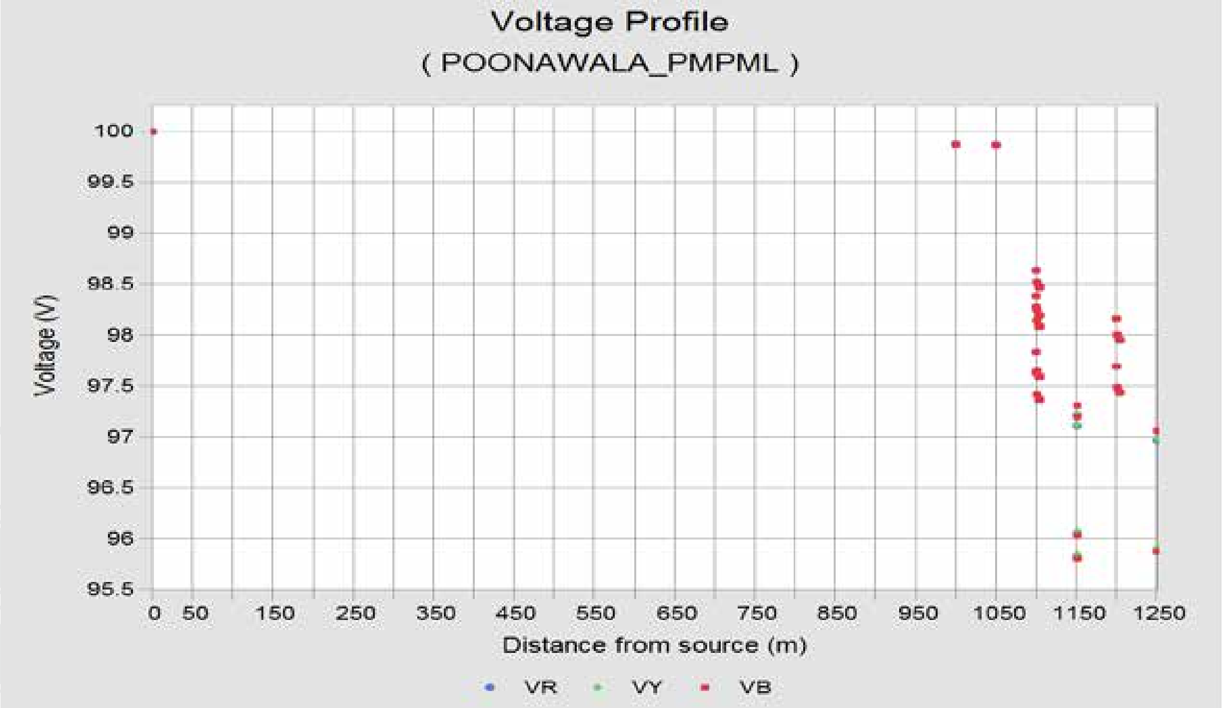


Figure 2-31: Voltage profile at Pune bus depot in 2024 scenario

2.5.6 Load Flow of 2027 Scenario of Pune Bus Depot

Total EVSE load of 12301.46 kW is considered for 2027 scenario, with AC chargers of 103x80 kW and DC chargers of 7x150 kW and 6x180 kW. Ten number of 1250 kVA PSS are required in this scenario. The model estimates the total losses at 377.21 kW. The number of overloaded and abnormal elements have also increased.

Table 2-14: Load flow summary of Pune bus depot of 2027 scenario

Study Parameters				
Calculation Method	Voltage Drop – Unbalanced			
Tolerance	0.01 %			
Load Factors	Global (P=100.00%, Q=100.00%)			
Shunt Capacitors	On			
Sensitivity Load Model	From Library			
Total Summary	**kW**	**kVAR**	**kVA**	**PF (%)**
Sources (Swing)	12678.67	1517.63	12769.17	99.29
Generators	0.00	0.00	0.00	0.00
Total Generation	**12678.67**	**1517.63**	**12769.17**	**99.29**
Load read (Non-adjusted)	10111.49	0.00	10111.49	100.00
Load used (Adjusted)	10111.46	0.00	10111.46	100.00
EVSE DC Load	**2190.00**	**1129.00**	**2589.00**	
Shunt capacitors (Adjusted)	0.00	0.00	0.00	0.00
Shunt reactors (Adjusted)	0.00	0.00	0.00	0.00
Motors	0.00	0.00	0.00	0.00
Total Loads	**12301.46**	**1129.00**	**12700.46**	**100.00**
Cable Capacitance	0.00	-46.78	46.78	0.00
Line Capacitance	0.00	0.00	0.00	0.00
Total Shunt Capacitance	**0.00**	**-46.78**	**46.78**	**0.00**
Line Losses	15.78	36.76	40.01	39.43
Cable Losses	56.13	27.95	62.70	89.52
Transformer Load Losses	171.88	382.13	419.01	41.02
Transformer No-Load Losses	15.94	0.00	15.94	100.00
Total Losses	**377.21**	**1564.41**	**1609.24**	**23.44**

Annual Cost of System Losses	kW	MW-h/year
Line Losses	15.78	138.19
Cable Losses	56.13	491.72
Transformer Load Losses	171.88	1505.69
Transformer No-Load Losses	15.94	139.64
Total Losses	377.21	3304.36

In this scenario, the difference between adjusted and non-adjusted loads mentioned in the above table is small and hence less abnormal condition (overloaded, under voltage) present in the network, which is under tolerance limits. In the network, there are five transformers overloaded; and one of them PSS-3 TFR is loaded 127.2%. Overloaded transformer is shown in the below figure.

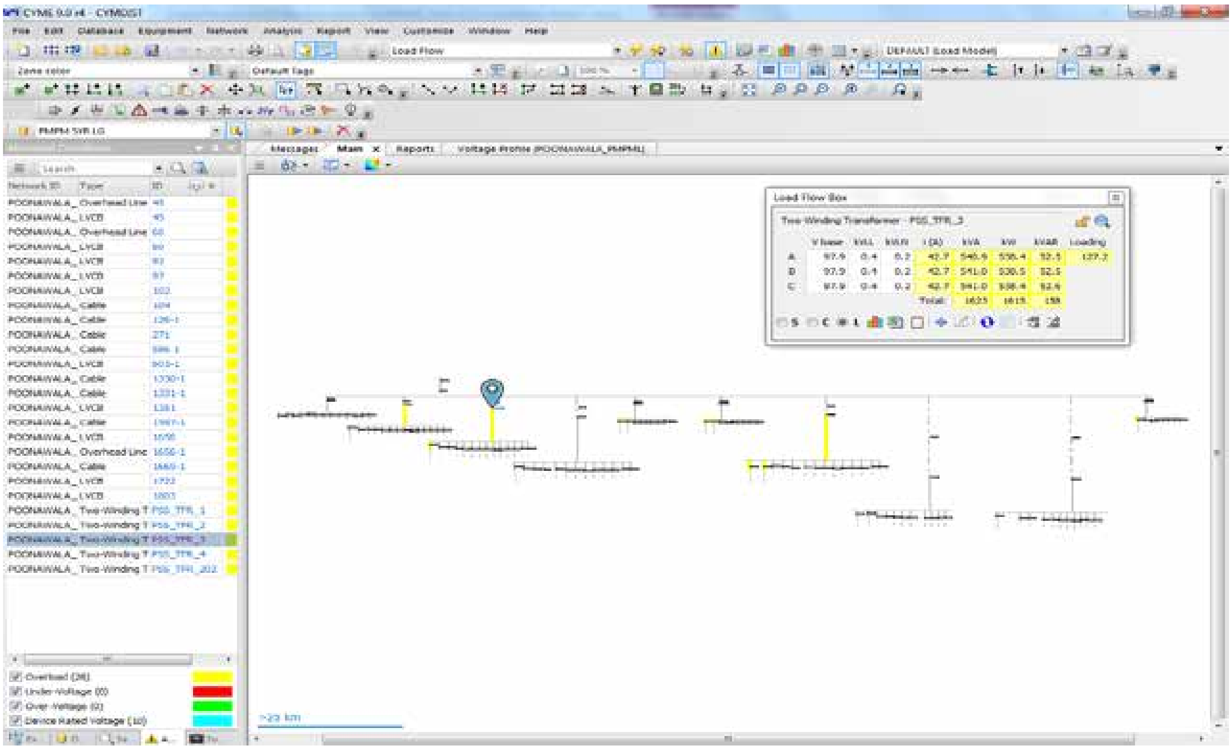


Figure 2-32: Over loaded transformer as PSS-3 in 2027 scenario

The voltage profile for 22 kV Poonawala Feeder from Phursungi 132/22 MUSS has been plotted in the figure below. There is a problem of low voltage (per unit) persisting in the feeder which drops the base voltage to 96.3 V per unit (compared to 100 V per unit) at a distance of 1251m from the feeder head.

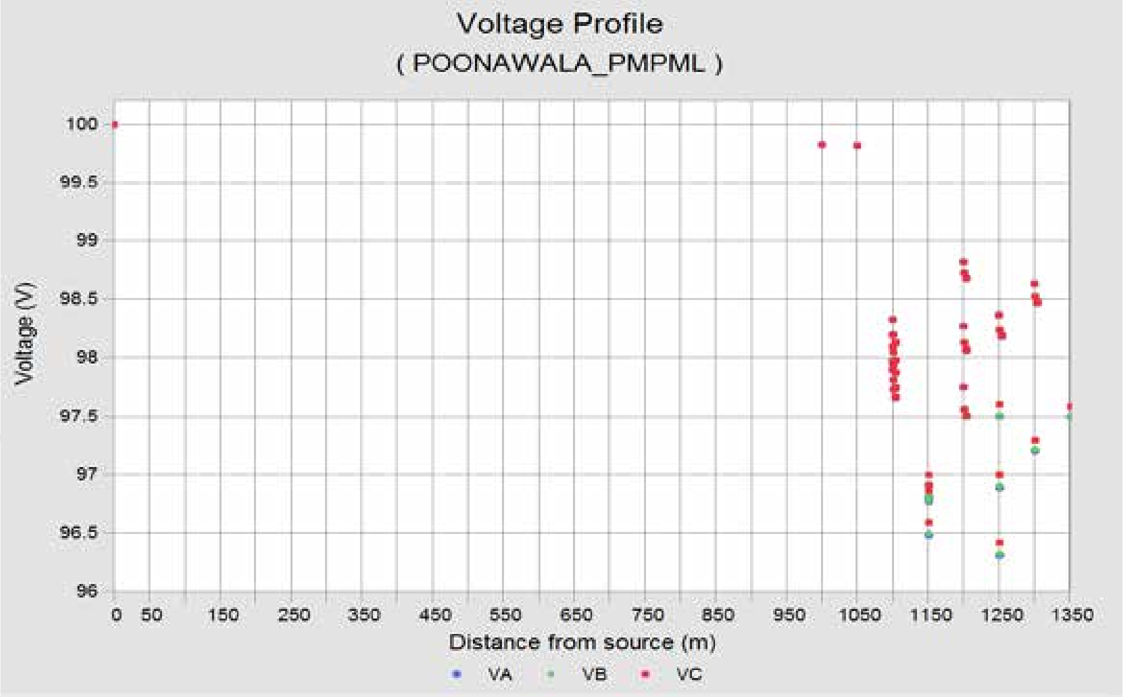


Figure 2-33: Voltage profile at Pune bus depot with EVSE in 2027 scenario

2.5.7 Harmonics Impact Study

The EVSE installed at the Bhekrainagar bus depot, Pune as of 2022 are given below:

Sl No	Particulars	No. of Units	Load of each unit	Total Load (kW)
1	DC Charger	5	150 kW x 2 Nos 180 kW x 3 Nos	840
2	AC Charger	58	80 kW	4640

The individual and total voltage and current harmonics details were captured by the PQM installed at Bhekrainagar bus depot, Pune, used for this model are listed in the Table below.

Table 2-15: Harmonics (%) injected by EVSE recorded by PQM

	% Voltage Source Harmonics			% Current Source Harmonics		
Harmonic Order	V_{RN}	V_{YN}	V_{BN}	V_{RN}	V_{YN}	V_{BN}
3rd	0.1585	0.1308	0.1944	1.663	0.622	1.120
5th	1.1112	1.1158	0.9617	4.410	4.920	5.179
7th	1.0206	0.9872	1.0350	0.866	0.651	0.771
9th	0.1133	0.0490	0.0672	0.239	0.207	0.181
11th	0.1068	0.1046	0.1299	0.609	1.046	1.014

2.5.8 Harmonic Analysis for As-Is 2022 scenario

Below is the harmonic voltage analysis report. The study indicates that the Total Harmonic Distortion (THD) lies between 2-5%.

Table 2-16: Voltage harmonic distortion analysis impact in As-Is 2022 scenario

Node ID	kV L-N	150.00 Hz IHD (%)	250.00 Hz IHD (%)	350.00 Hz IHD (%)	450.00 Hz IHD (%)	550.00 Hz IHD (%)	THD (%)	KVT (kV)	TIF
PSS-1 CHARGING PANEL-A	0.25	0.516	3.649	3.362	0.360	0.350	5.014	3.56	14.43
PSS-2 CHARGING PANEL-A	0.25	0.497	3.488	3.195	0.343	0.337	4.780	3.38	13.75
PSS-3 CHARGING PANEL-A	0.24	0.493	3.425	3.136	0.335	0.326	4.693	3.29	13.47
PSS-4 CHARGING PANEL-A	0.25	0.457	3.197	2.937	0.316	0.311	4.388	3.11	12.64
PSS-5 CHARGING PANEL-A	0.24	0.308	2.029	1.810	0.197	0.216	2.752	1.94	7.95

Below is the harmonic current analysis report, after analyzing the impact at the PSS and its nearby network at the Poonawala feeder. The study indicates that the Individual Harmonic Distortion (IHD) lies between 1-2% near the EVSE station.

Table 2-17: Current harmonic distortion analysis impact in As-Is 2022 scenario

Device Number	Device Type	Fund. Current (A)	150.00 Hz IHD (%)	250.00 Hz IHD (%)	350.00 Hz IHD (%)	450.00 Hz IHD (%)	550.00 Hz IHD (%)	THD (%)	KIT (kA)	ITIF	PCC	Isc/I$_L$	TDD (%)
PSS_TFR_1-A	Two-Winding Transformer	28.17	0.896	2.242	0.151	0.363	0.142	2.451	0.13	4.56	PSS_TFR_1-A	2774.85	2.451
PSS_TFR_2-A	Two-Winding Transformer	32.69	0.725	1.824	0.123	0.296	0.119	1.992	0.12	3.75	PSS_TFR_2-A	2391.34	1.992
PSS_TFR_3-A	Two-Winding Transformer	34.60	0.671	1.692	0.115	0.271	0.108	1.847	0.12	3.45	PSS_TFR_3-A	2258.96	1.847
PSS_TFR_4-A	Two-Winding Transformer	30.49	0.714	1.799	0.122	0.293	0.119	1.966	0.11	3.72	PSS_TFR_4-A	2563.91	1.966
PSS_TFR_5-A	Two-Winding Transformer	29.69	0.466	1.162	0.086	0.186	0.131	1.275	0.08	2.84	PSS_TFR_5-A	2632.82	1.275

The results monitored at PSS charging panel presented in the below figures.

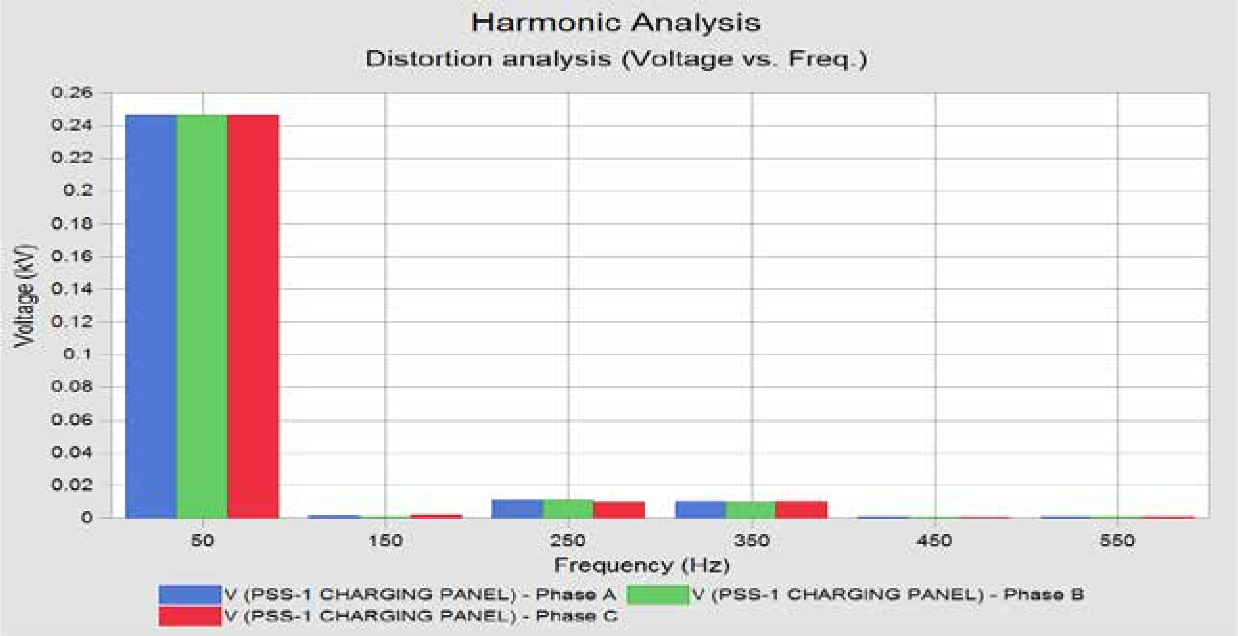


Figure 2-34: Voltage distortion at PSS in 2022 scenario

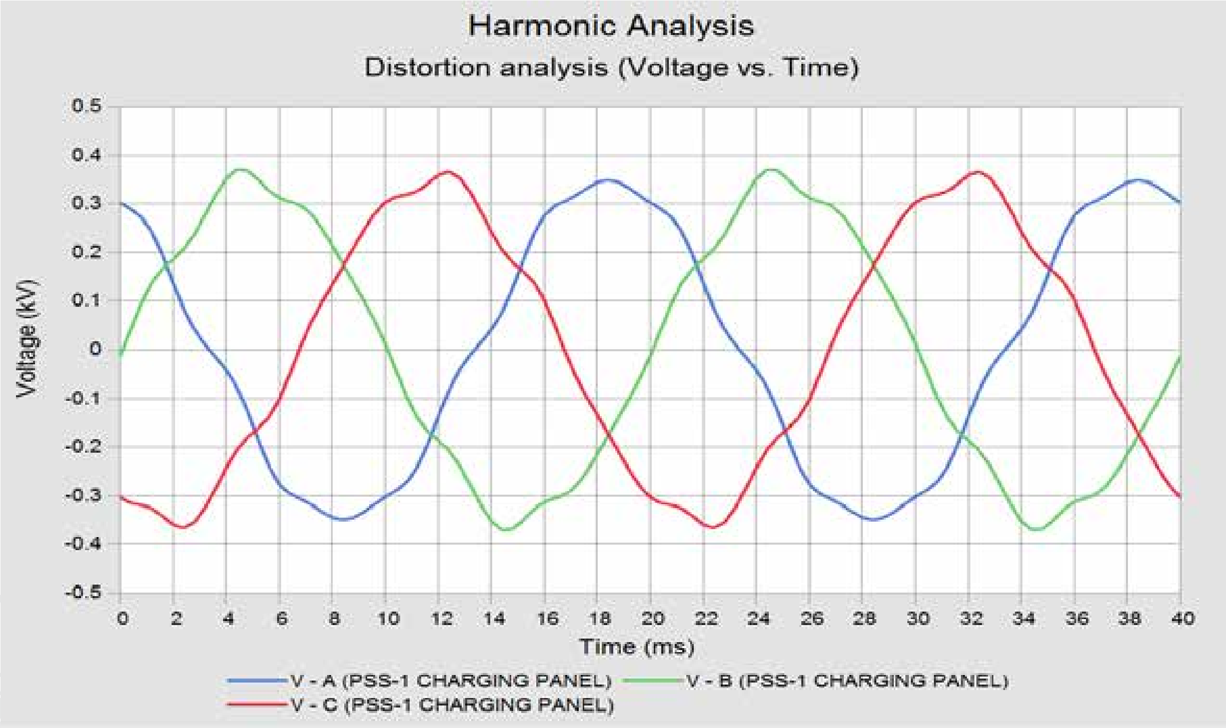


Figure 2-35: Voltage distortion at PSS in 2022 scenario

Referring to the results in above figures, it has been observed that the voltage distortions are within the limit for 5th and 7th order frequencies on the LT side of the EVSE transformer in time domain and frequency domain and are acceptable as per IEEE 519 limits.

2.5.9 Harmonic Analysis for As-Is 2022 scenario (As per Load Measured by PQM)

For this scenario, the inputs considered as per the data recorded by the PQM on 29 July 2022 with active power of 3821.79 kW is taken for load flow study analysis, where EVSE considered are 44x80 kW AC chargers, 1x150 kW DC chargers and 1x180 kW DC chargers to match the active power of 3821.79 kW. Below is the harmonic voltage analysis report after analyzing the impact at the PSS and its nearby network. The study indicates that the Total Harmonic Distortion (THD) lies between 2-5% near the EVSE station.

Table 2-18: Voltage harmonic distortion analysis impact in 2022 scenario (as per PQM)

Node ID	kV L-N	150.00 Hz IHD (%)	250.00 Hz IHD (%)	350.00 Hz IHD (%)	450.00 Hz IHD (%)	550.00 Hz IHD (%)	THD (%)	KVT (kV)	TIF
PSS-1 CHARGING PANEL-A	0.25	0.510	3.599	3.239	0.368	0.318	4.893	3.43	13.89
PSS-2 CHARGING PANEL-A	0.25	0.510	3.599	3.239	0.368	0.318	4.893	3.43	13.89
PSS-3 CHARGING PANEL-A	0.25	0.510	3.599	3.239	0.368	0.318	4.893	3.43	13.89
PSS-4 CHARGING PANEL-A	0.25	0.465	3.263	2.943	0.337	0.293	4.441	3.11	12.64
PSS-5 CHARGING PANEL-A	0.25	0.265	1.848	1.657	0.202	0.167	2.510	1.76	7.17

Below is the harmonic current analysis report after analyzing the impact at the PSS and its nearby network at the Poonawala feeder. The study indicates that the individual Harmonic Distortion (IHD) lies between 1.6-2.6%.

Table 2-19: Current harmonic distortion analysis impact in 2022 scenario (as per PQM)

Device Number	Device Type	Fund. Current (A)	150.00 Hz IHD (%)	250.00 Hz IHD (%)	350.00 Hz IHD (%)	450.00 Hz IHD (%)	550.00 Hz IHD (%)	THD (%)	KIT (kA)	ITIF	PCC	Isc/IL	TDD (%)
PSS_TFR_1-A	Two-Winding Transformer	21.65	0.948	2.373	0.160	0.389	0.155	2.594	0.11	4.88	PSS_TFR_1-A	653.54	2.594
PSS_TFR_2-A	Two-Winding Transformer	21.65	0.948	2.373	0.160	0.389	0.155	2.594	0.11	4.88	PSS_TFR_2-A	653.54	2.594
PSS_TFR_3-A	Two-Winding Transformer	21.65	0.948	2.373	0.160	0.389	0.155	2.594	0.11	4.88	PSS_TFR_3-A	653.54	2.594
PSS_TFR_4-A	Two-Winding Transformer	23.96	0.763	1.923	0.131	0.317	0.131	2.101	0.10	4.01	PSS_TFR_4-A	590.45	2.101
PSS_TFR_5-A	Two-Winding Transformer	17.68	0.588	1.483	0.106	0.239	0.124	1.621	0.06	3.24	PSS_TFR_5-A	800.25	1.621

The results monitored at PSS charging panel presented in the below figures.

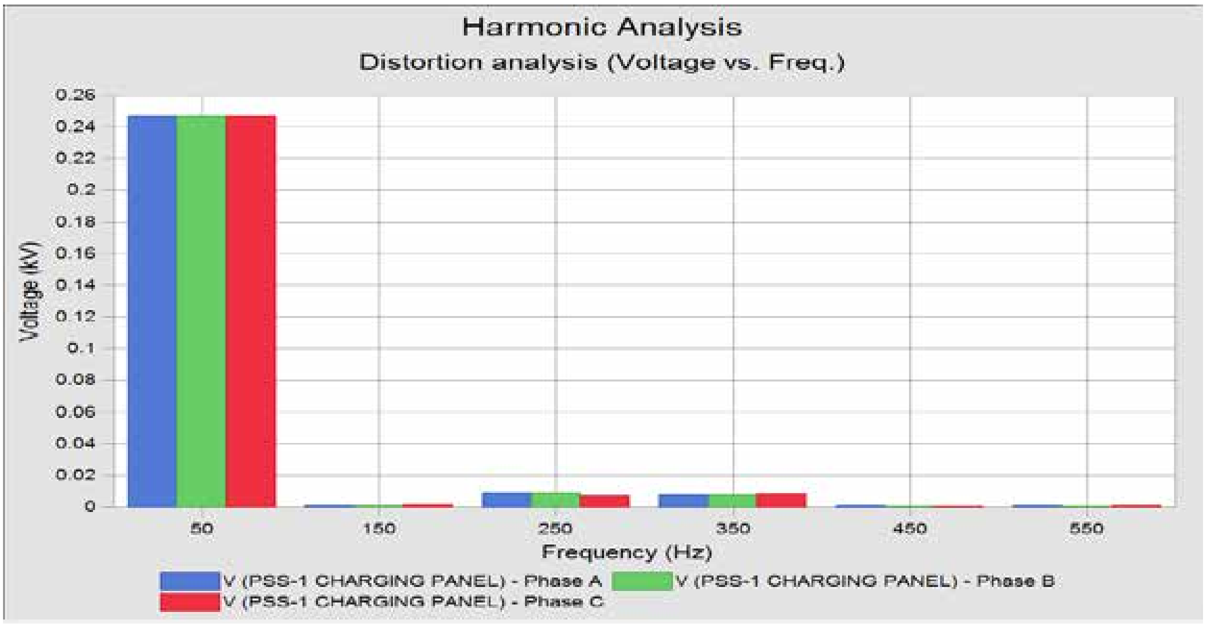


Figure 2-36: Voltage distortion at PSS in 2022 (as per PQM) scenario

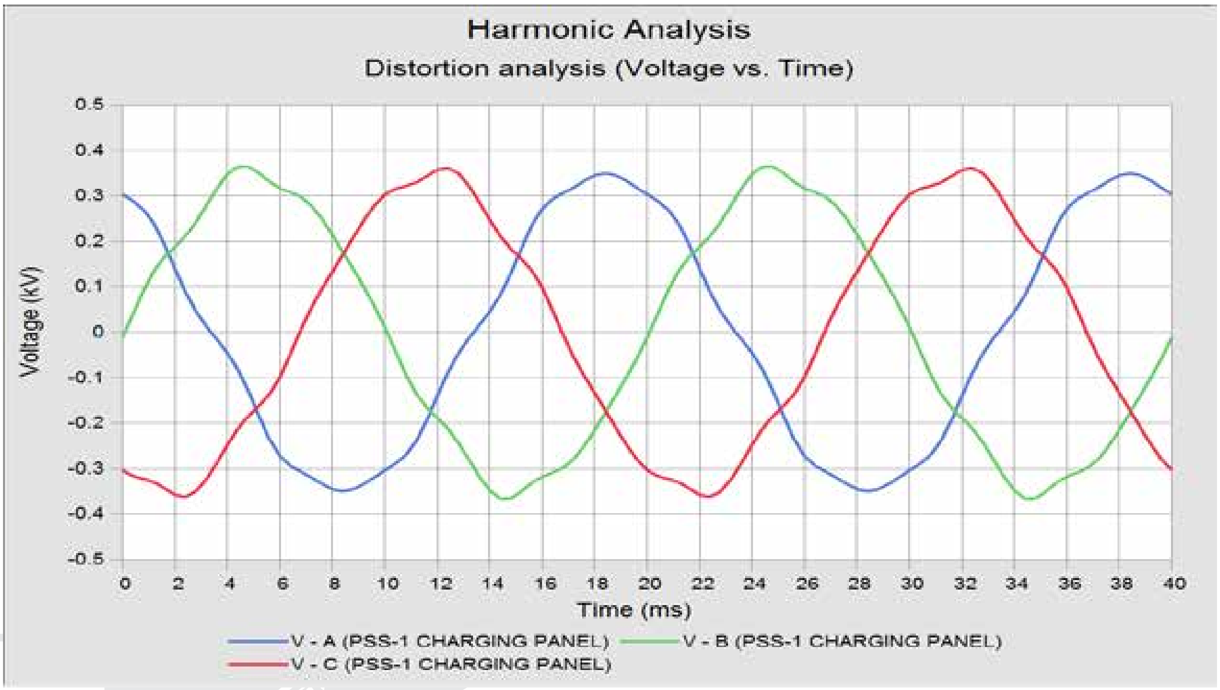


Figure 2-37: Voltage distortion at PSS in 2022 (as per PQM) scenario

Referring to the results in above Figures, it has been observed that the voltage distortions are within the limit for 5th and 7th order frequencies on the LT side of the PSS in time domain and frequency domain and are acceptable as per IEEE 519 limits.

2.5.10 Harmonic Analysis for 2024 scenario

For 2024 projected scenario, with the total load of 8235 kW, where AC chargers of 77x80 kW and DC chargers of 4x150 kW, 5x180 kW and seven number of 1250 kVA PSS are required in the scenario as shown in below Table.

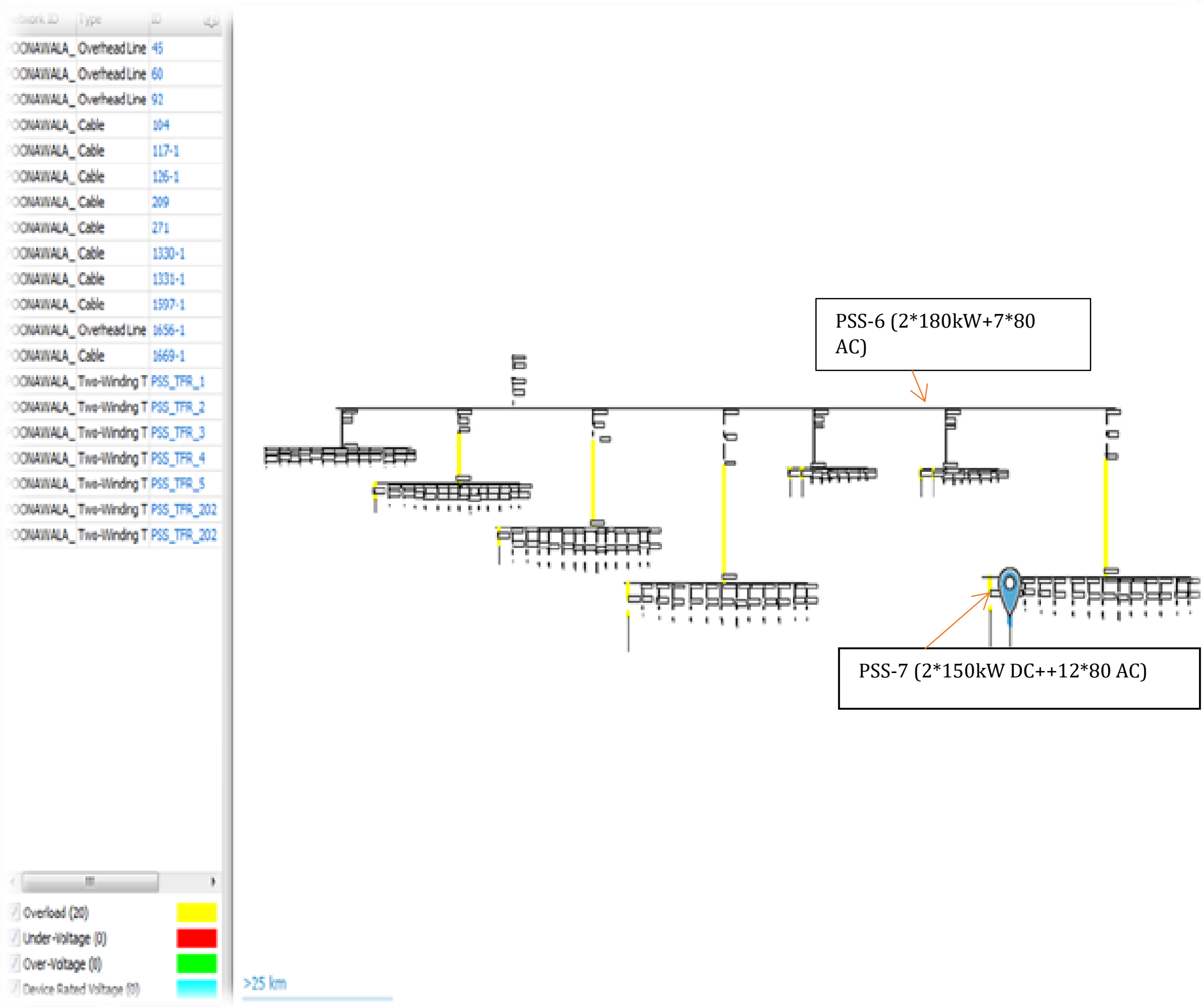
Table 2-20: List of chargers considered at Pune bus depot in 2024 scenario

Network Id	Equipment Id	Type	Nominal Power (kW)	Input Voltage (kVLL)	Output Voltage (V)	PF (%)	Efficiency (A)	Ctrl Type	Operating Voltage (V)	Operating PF (%)
PSS-2 DC CHARGERS -1	DC CHARGERS_150 kW	Battery Chargers	150	0.4	750.0	90.0	95.0	Fixed Voltage	750.0	95
PSS-3 DC CHARGERS-2	DC CHARGERS_180 kW	Battery Chargers	180	0.4	750.0	90.0	95.0	Fixed Voltage	750.0	95
PSS-4 DC CHARGERS-3	DC CHARGERS_150 kW	Battery Chargers	150	0.4	750.0	90.0	95.0	Fixed Voltage	750.0	95
PSS-5 DC CHARGERS-4	DC CHARGERS_180 kW	Battery Chargers	180	0.4	750.0	90.0	95.0	Fixed Voltage	750.0	95
PSS-5 DC CHARGERS-5	DC CHARGERS_180 kW	Battery Chargers	180	0.4	750.0	90.0	95.0	Fixed Voltage	750.0	95
PSS-6 DC CHARGERS-6_2024	DC CHARGERS_180 kW	Battery Chargers	180	0.4	750.0	90.0	95.0	Fixed Voltage	750.0	95
PSS-6 DC CHARGERS-7_2024	DC CHARGERS_180 kW	Battery Chargers	180	0.4	750.0	90.0	95.0	Fixed Voltage	750.0	95
PSS-7 DC CHARGERS-8_2024	DC CHARGERS_150 kW	Battery Chargers	150	0.4	750.0	90.0	95.0	Fixed Voltage	750.0	95
PSS-7 DC CHARGERS-9_2024	DC CHARGERS_150 kW	Battery Chargers	150	0.4	750.0	90.0	95.0	Fixed Voltage	750.0	95
PSS-1 AC CHARGERS -1 to13	AC CHARGERS_80 kW		80	0.4				Fixed Voltage	430	95
PSS-2 AC CHARGERS -14 to 26	AC CHARGERS_80 kW		80	0.4				Fixed Voltage	430	95
PSS-3 AC CHARGERS -27 to 39	AC CHARGERS_80 kW		80	0.4				Fixed Voltage	430	95
PSS-4 AC CHARGERS -40 to 51	AC CHARGERS_80 kW		80	0.4				Fixed Voltage	430	95
PSS-5 AC CHARGERS -52 to58	AC CHARGERS_80 kW		80	0.4				Fixed Voltage	430	95
PSS-6 AC CHARGERS -59 to 65_2024	AC CHARGERS_80 kW		80	0.4				Fixed Voltage	430	95
PSS-7 AC CHARGERS -66 to 77_2024	AC CHARGERS_80 kW		80	0.4				Fixed Voltage	430	95

Table 2-21: EVSE details considered at Pune bus depot in 2024 scenario

AC and DC Loads					
Network Id	**Section Id**	**Status**	**Rated Voltage (V)**	**Rated Power (kW)**	**Rated current (A)**
PSS-2	PSS-2 DC -1	Connected	750.0	150.0	200.00
PSS-3	PSS-3 DC -2	Connected	750.0	180.0	240.00
PSS-4	PSS- 4 DC -3	Connected	750.0	150.0	200.00
PSS-5	PSS-5 DC -4	Connected	750.0	180.0	240.00
PSS-5	PSS-5 DC -5	Connected	750.0	180.0	240.00
PSS-6_2024	PSS-6 DC -6_2024	Connected	750.0	180.0	240.00
PSS-6_2024	PSS-6 DC -7_2024	Connected	750.0	180.0	240.00
PSS-7_2024	PSS-7 DC -9_2024	Connected	750.0	150.0	200.00
PSS-7_2024	PSS-7 DC -8_2024	Connected	750.0	150.0	200.00
PSS-1 AC CHARGERS -1 to13	AC CHARGERS_80 kW	Connected	430	80	
PSS-2 AC CHARGERS -14 to 26	AC CHARGERS_80 kW	Connected	430	80	
PSS-3 AC CHARGERS -27 to 39	AC CHARGERS_80 kW	Connected	430	80	
PSS-4 AC CHARGERS -40 to 51	AC CHARGERS_80 kW	Connected	430	80	
PSS-5 AC_2024 CHARGERS -52 to 58	AC CHARGERS_80 kW	Connected	430	80	
PSS-6 AC_2024 CHARGERS -59 to 65	AC CHARGERS_80 kW	Connected	430	80	
PSS-7 AC_2024 CHARGERS -66 to 77	AC CHARGERS_80 kW	Connected	430	80	

In this case, the harmonics are injected in to the distribution feeder by the EVSE installed at the bus depot. The losses and abnormal conditions in the feeder have increased due to harmonic current injection. The voltage amplitudes are within the limits for 5th and 7th order harmonics. It was observed that, voltage further drops to undesirable level and in that case, harmonics in the neutral conductor increases than the harmonics in the phase.



twork ID	Type	ID
OONAWALA_	Overhead Line	45
OONAWALA_	Overhead Line	60
OONAWALA_	Overhead Line	92
OONAWALA_	Cable	104
OONAWALA_	Cable	117-1
OONAWALA_	Cable	126-1
OONAWALA_	Cable	209
OONAWALA_	Cable	271
OONAWALA_	Cable	1330-1
OONAWALA_	Cable	1331-1
OONAWALA_	Cable	1597-1
OONAWALA_	Overhead Line	1656-1
OONAWALA_	Cable	1669-1
OONAWALA_	Two-Winding T	PSS_TFR_1
OONAWALA_	Two-Winding T	PSS_TFR_2
OONAWALA_	Two-Winding T	PSS_TFR_3
OONAWALA_	Two-Winding T	PSS_TFR_4
OONAWALA_	Two-Winding T	PSS_TFR_5
OONAWALA_	Two-Winding T	PSS_TFR_202
OONAWALA_	Two-Winding T	PSS_TFR_202

☑ Overload (20)	🟨
☑ Under-Voltage (0)	🟥
☑ Over-Voltage (0)	🟩
☑ Device Rated Voltage (0)	🟦

PSS-6 (2*180kW+7*80 AC)

PSS-7 (2*150kW DC++12*80 AC)

Figure 2-38: Network conditions post harmonic analysis in 2024 scenario

Below is the harmonic voltage distortion report after analysing the impact at the PSS and its nearby network. The study indicates that the Total Harmonic Distortion (THD) lies 3-6%.

Table 2-22: Voltage harmonic distortion analysis impact in year 2024 scenario

Node ID	kV L-N	150.00 Hz IHD (%)	250.00 Hz IHD (%)	350.00 Hz IHD (%)	450.00 Hz IHD (%)	550.00 Hz IHD (%)	THD (%)	KVT (kV)	TIF
PSS-1 CHARGING PANEL-A	0.25	0.709	4.921	4.458	0.469	0.439	6.709	4.69	19.01
PSS-2 CHARGING PANEL-A	0.25	0.714	4.937	4.463	0.469	0.446	6.725	4.68	19.07
PSS-3 CHARGING PANEL-A	0.24	0.717	4.937	4.453	0.467	0.461	6.719	4.67	19.10
PSS-4 CHARGING PANEL-A	0.25	0.660	4.576	4.144	0.439	0.419	6.239	4.36	17.74
PSS-5 CHARGING PANEL-A	0.24	0.407	2.748	2.478	0.269	0.335	3.747	2.70	11.08
PSS-6_2024 CHARGING PANEL-A	0.24	0.407	2.750	2.481	0.269	0.339	3.751	2.71	11.12
PSS-7_2024 CHARGING PANEL-A	0.24	0.668	4.608	4.171	0.444	0.438	6.282	4.40	17.93

Below is the **harmonic current distortion** report after analysing the impact at the PSS and its nearby network at the Poonawala feeder. The study indicates that the Individual Harmonic Distortion (IHD) lies 1.36-2.5%.

Table 2-23: Current harmonic distortion analysis impact in 2024 scenario

Device Number	Device Type	Fund. Current (A)	150.00 Hz IHD (%)	250.00 Hz IHD (%)	350.00 Hz IHD (%)	450.00 Hz IHD (%)	550.00 Hz IHD (%)	THD (%)	KIT (kA)	ITIF	PCC	Isc/IL	TDD (%)
PSS_TFR_1-A	Two-Winding Transformer	31.68	0.890	2.217	0.149	0.357	0.135	2.424	0.14	4.47	PSS_TFR_1-A	2465.09	2.424
PSS_TFR_2-A	Two-Winding Transformer	36.21	0.770	1.926	0.129	0.310	0.130	2.105	0.14	3.97	PSS_TFR_2-A	2156.31	2.105
PSS_TFR_3-A	Two-Winding Transformer	38.09	0.728	1.827	0.123	0.292	0.140	1.997	0.15	3.87	PSS_TFR_3-A	2049.74	1.997
PSS_TFR_4-A	Two-Winding Transformer	33.73	0.764	1.917	0.129	0.311	0.132	2.095	0.13	3.98	PSS_TFR_4-A	2314.80	2.095
PSS_TFR_5-A	Two-Winding Transformer	31.41	0.493	1.236	0.090	0.198	0.177	1.360	0.11	3.38	PSS_TFR_5-A	2485.84	1.360
PSS_2024_TFR_6-A	Two-Winding Transformer	29.70	0.523	1.312	0.095	0.211	0.191	1.444	0.11	3.61	PSS_2024_TFR_6-A	2628.99	1.444
PSS_2024_TFR_7-A	Two-Winding Transformer	35.14	0.730	1.841	0.125	0.301	0.147	2.013	0.14	3.98	PSS_2024_TFR_7-A	2222.06	2.013

The results monitored at PSS charging panel presented in the below figures.

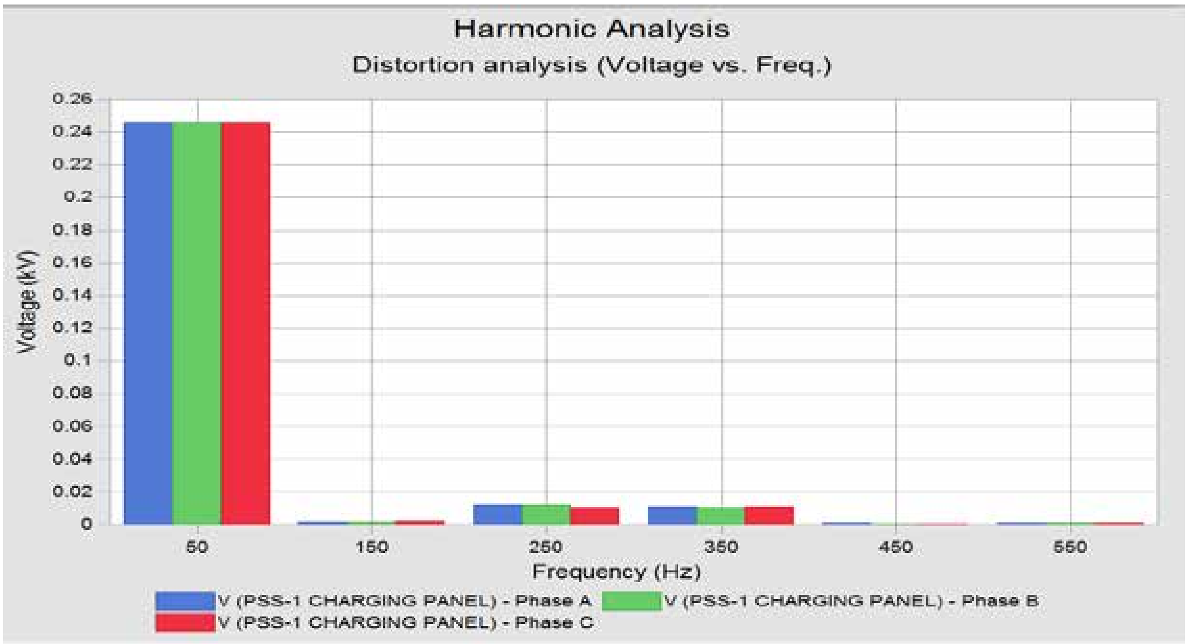


Figure 2-39: Voltage distortion at PSS connected to EVSE in 2024 Scenario

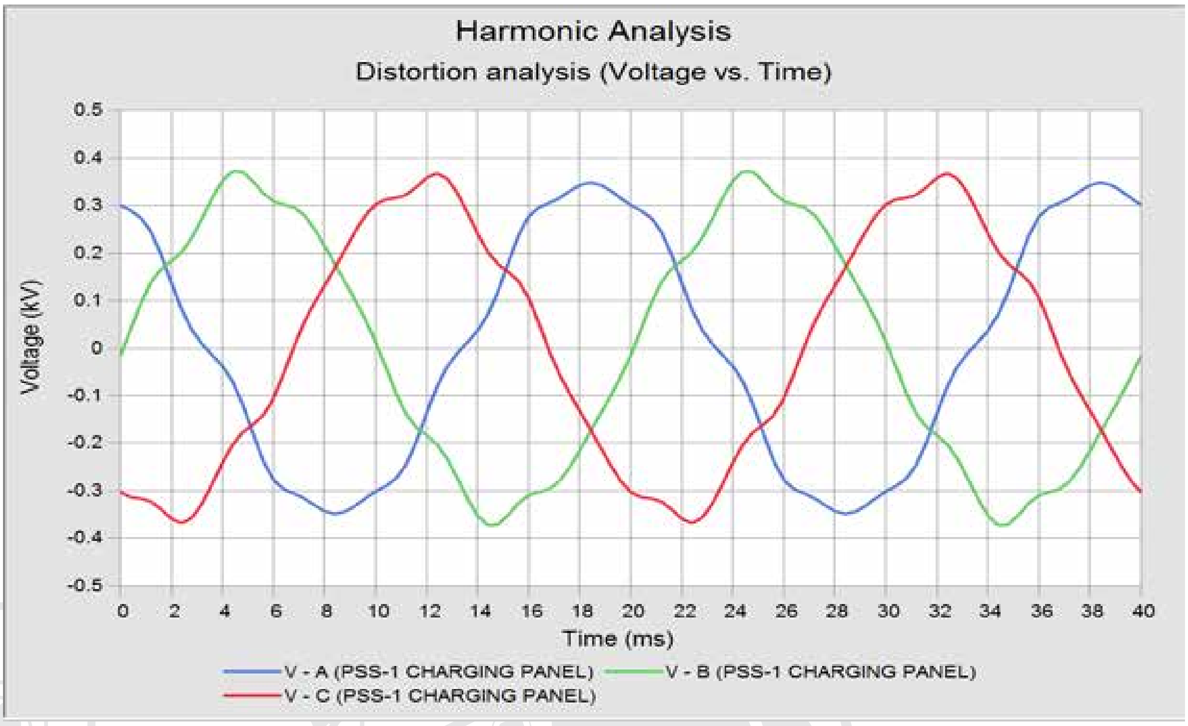


Figure 2-40: Voltage distortion at PSS connected to EVSE in 2024 Scenario

Referring to the results in above figures, it has been observed that the voltage distortions are within the limit for 5th and 7th order frequencies on the LT side of the PSS in time domain and frequency domain and are acceptable as per IEEE 519 limits.

2.5.11 Harmonic Analysis for 2027 scenario

For 2027 projected scenario, the total load of 12251 kW has been considered with EVSE consisting of AC chargers of 103x 80 kW and DC chargers of 7x150 kW and 6x180 kW and 10 number of 1250 kVA PSS are required in the scenario as mentioned in the below table.

Table 2-24: List Chargers considered at Pune bus depot in 2027 scenario

Chargers										
Network Id	Equipment Id	Type	Nominal Power	Input Voltage	Output Voltage	PF	Efficiency	Ctrl Type	Operating Voltage	Operating PF
			(kW)	(kV_{LL})	(V)	(%)	(A)		(V)	(%)
PSS-2 DC CHARGERS -1	DC CHARGERS_150 kW	Battery Chargers	150	0.4	750	90	95	Fixed Voltage	750	95
PSS-3 DC CHARGERS -2	DC CHARGERS_180 kW	Battery Chargers	180	0.4	750	90	95	Fixed Voltage	750	95
PSS-4 DC CHARGERS -3	DC CHARGERS_150 kW	Battery Chargers	150	0.4	750	90	95	Fixed Voltage	750	95
PSS-5 DC CHARGERS -4	DC CHARGERS_180 kW	Battery Chargers	180	0.4	750	90	95	Fixed Voltage	750	95
PSS-5 DC CHARGERS -5	DC CHARGERS_180 kW	Battery Chargers	180	0.4	750	90	95	Fixed Voltage	750	95
PSS-6 DC CHARGERS-6_2024	DC CHARGERS_180 kW	Battery Chargers	180	0.4	750	90	95	Fixed Voltage	750	95
PSS-6 DC CHARGERS-7_2024	DC CHARGERS_180 kW	Battery Chargers	180	0.4	750	90	95	Fixed Voltage	750	95
PSS-7 DC CHARGERS-8_2024	DC CHARGERS_150 kW	Battery Chargers	150	0.4	750	90	95	Fixed Voltage	750	95
PSS-7 DC CHARGERS-9_2024	DC CHARGERS_150 kW	Battery Chargers	150	0.4	750	90	95	Fixed Voltage	750	95
PSS-8 DC CHARGERS-10_2027	DC CHARGERS_150 kW	Battery Chargers	150	0.4	750	90	95	Fixed Voltage	750	95
PSS-8 DC CHARGERS-11_2027	DC CHARGERS_150 kW	Battery Chargers	150	0.4	750	90	95	Fixed Voltage	750	95
PSS-9 DC CHARGERS-12_2027	DC CHARGERS_150 kW	Battery Chargers	150	0.4	750	90	95	Fixed Voltage	750	95
PSS-10 DC CHARGERS-13_2027	DC CHARGERS_180 kW	Battery Chargers	180	0.4	750	90	95	Fixed Voltage	750	95
PSS-1 AC CHARGERS -1 to13	AC CHARGERS_80 kW		80	0.4				Fixed Voltage	0.4	95
PSS-2 AC CHARGERS -14 to 26	AC CHARGERS_80 kW		80	0.4				Fixed Voltage	0.4	95
PSS-3 AC CHARGERS -27 to 39	AC CHARGERS_80 kW		80	0.4				Fixed Voltage	0.4	95

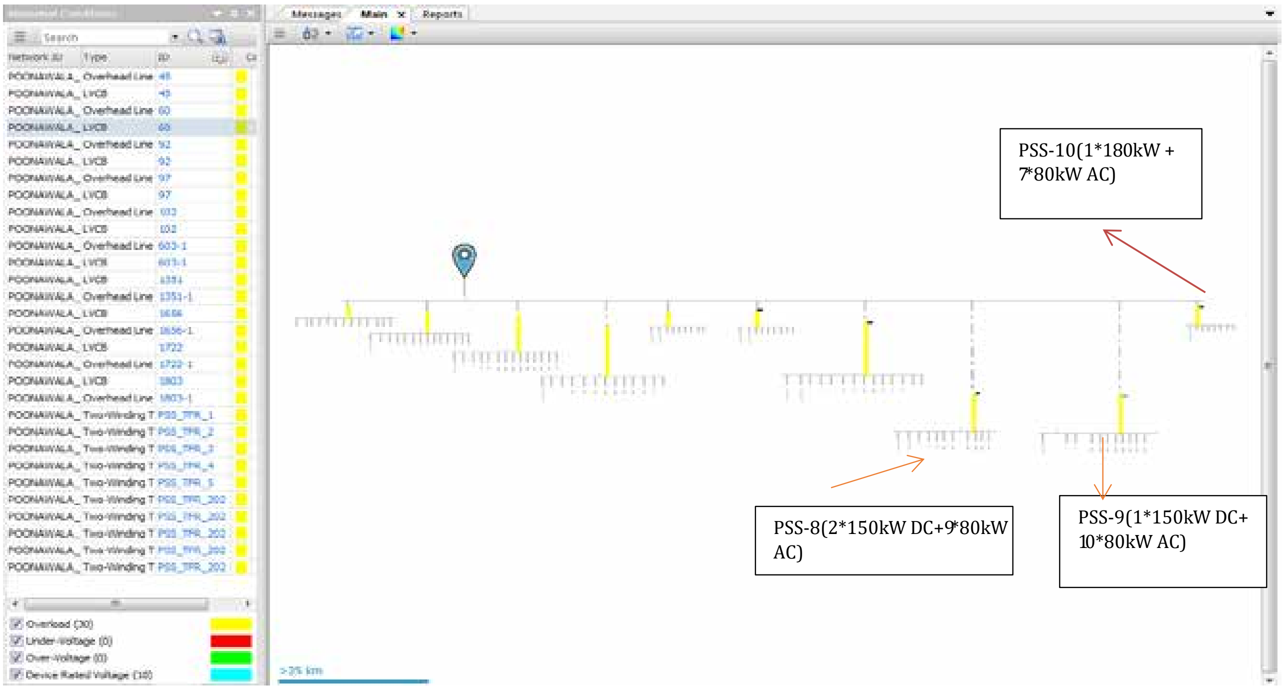
PSS-4 AC CHARGERS -40 to 51	AC CHARGERS_80 kW		80	0.4				Fixed Voltage	0.4	95
PSS-5 AC CHARGERS -52 to58	AC CHARGERS_80 kW		80	0.4				Fixed Voltage	0.4	95
PSS-6 AC CHARGERS -59 to 65_2024	AC CHARGERS_80 kW		80	0.4				Fixed Voltage	0.4	95
PSS-7 AC CHARGERS -66 to 77_2024	AC CHARGERS_80 kW		80	0.4				Fixed Voltage	0.4	95
PSS-8 AC CHARGERS -78 to 86_2027	AC CHARGERS_80 kW		80	0.4				Fixed Voltage	0.4	95
PSS-9 AC CHARGERS -87 to 96_2027	AC CHARGERS_80 kW		80	0.4				Fixed Voltage	0.4	95
PSS-10 AC CHARGERS -97 to 103_2027	AC CHARGERS_80 kW		80	0.4				Fixed Voltage	0.4	95

Table 2-25: EVSE details considered at Pune bus depot in 2027 scenario

Network Id	Section Id	Status	Rated Voltage (V)	Rated Power (kW)	Rated current (A)
PSS-2	PSS-2 DC -1	Connected	750.0	150.0	200.00
PSS-3	PSS-3 DC -2	Connected	750.0	180.0	240.00
PSS-4	PSS-4 DC -3	Connected	750.0	150.0	200.00
PSS-5	PSS-5 DC -4	Connected	750.0	180.0	240.00
PSS-5	PSS-5 DC -5	Connected	750.0	180.0	240.00
PSS-6_2024	PSS-6 DC -6	Connected	750.0	180.0	240.00
PSS-6 _2024	PSS-6 DC -7	Connected	750.0	180.0	240.00
PSS-7_2024	PSS-7 DC -8	Connected	750.0	150.0	240.00
PSS-7_2024	PSS-7 DC -9	Connected	750.0	150.0	240.00
PSS-8_2027	PSS-8 DC -10	Connected	750.0	150.0	200.00
PSS-8_2027	PSS-8 DC -11	Connected	750.0	150.0	200.00
PSS-9 _2027	PSS-9 DC -12	Connected	750.0	150.0	200.00
PSS-10_2027	PSS-10 DC -13	Connected	750.0	180.0	240.00
PSS-1 AC CHARGERS -1 to13	AC CHARGERS_80 kW	Connected	430	80	
PSS-2 AC CHARGERS -14 to 26	AC CHARGERS_80 kW	Connected	430	80	

PSS-3 AC CHARGERS -27 to 39	AC CHARGERS_80 kW	Connected	430	80	
PSS-4 AC CHARGERS -40 to 51	AC CHARGERS_80 kW	Connected	430	80	
PSS-5 AC CHARGERS -52 to58	AC CHARGERS_80 kW	Connected	430	80	
PSS-6 AC CHARGERS -59 to 65_2024	AC CHARGERS_80 kW	Connected	430	80	
PSS-7 AC CHARGERS -66 to 77_2024	AC CHARGERS_80 kW	Connected	430	80	
PSS-8 AC CHARGERS -78 to 86_2027	AC CHARGERS_80 kW	Connected	430	80	
PSS-9 AC CHARGERS -87 to 96_2027	AC CHARGERS_80 kW	Connected	430	80	
PSS-10 AC CHARGERS -97 to 103_2027	AC CHARGERS_80 kW	Connected	430	80	

In this case, the harmonics are injected in to the distribution feeder by the EVSE. The losses and abnormal conditions in the feeders have increased due to harmonic current injection. The voltage harmonics are within the limits for 5th and 7th order harmonics. It was observed that, voltage further drops near to undesirable level and in that case, harmonics in the neutral conductor increases than the harmonics in the phase.



Network ID	Type	ID
POONAWALA_	Overhead Line	48
POONAWALA_	LVCB	48
POONAWALA_	Overhead Line	60
POONAWALA_	LVCB	60
POONAWALA_	Overhead Line	92
POONAWALA_	LVCB	92
POONAWALA_	Overhead Line	97
POONAWALA_	LVCB	97
POONAWALA_	Overhead Line	102
POONAWALA_	LVCB	102
POONAWALA_	Overhead Line	603-1
POONAWALA_	LVCB	603-1
POONAWALA_	LVCB	1351
POONAWALA_	Overhead Line	1351-1
POONAWALA_	LVCB	1656
POONAWALA_	Overhead Line	1656-1
POONAWALA_	LVCB	1722
POONAWALA_	Overhead Line	1722-1
POONAWALA_	LVCB	1803
POONAWALA_	Overhead Line	1803-1
POONAWALA_	Two-Winding T	PSS_TFR_1
POONAWALA_	Two-Winding T	PSS_TFR_2
POONAWALA_	Two-Winding T	PSS_TFR_3
POONAWALA_	Two-Winding T	PSS_TFR_4
POONAWALA_	Two-Winding T	PSS_TFR_5
POONAWALA_	Two-Winding T	PSS_TFR_202
POONAWALA_	Two-Winding T	PSS_TFR_202
POONAWALA_	Two-Winding T	PSS_TFR_202
POONAWALA_	Two-Winding T	PSS_TFR_202
POONAWALA_	Two-Winding T	PSS_TFR_202

☑ Overload (30) 🟨
☑ Under-Voltage (0) 🟥
☑ Over-Voltage (0) 🟩
☑ Device Rated Voltage (10) 🟦

Figure 2-41: Network Conditions post Harmonic Analysis in 2027 Scenario

Below is the **harmonic voltage distortion** report after analysing the impact at the PSS and its nearby network at the Poonawala feeder. The study indicates that the Total Harmonic Distortion (THD) lies 3-7%.

Table 2-26: Voltage harmonic distortion analysis impact in 2027 scenario

Node ID	kV L-N	150.00 Hz IHD (%)	250.00 Hz IHD (%)	350.00 Hz IHD (%)	450.00 Hz IHD (%)	550.00 Hz IHD (%)	THD (%)	KVT (kV)	TIF
PSS-1 CHARGING PANLE-A	0.25	0.669	4.620	4.143	0.429	0.390	6.268	4.33	17.61
PSS-2 CHARGING PANLE-A	0.24	0.674	4.643	4.147	0.432	0.399	6.289	4.32	17.67
PSS-3 CHARGING PANLE-A	0.24	0.675	4.643	4.147	0.432	0.400	6.289	4.32	17.67
PSS-4 CHARGING PANLE-A	0.24	0.623	4.309	3.861	0.404	0.377	5.846	4.04	16.48
PSS-5 CHARGING PANLE-A	0.24	0.380	2.599	2.332	0.257	0.264	3.532	2.49	10.17
PSS-6_2024 CHARGING PANLE-A	0.25	0.380	2.603	2.339	0.258	0.265	3.540	2.50	10.20
PSS-7_2024 CHARGING PANLE-A	0.24	0.632	4.343	3.916	0.412	0.396	5.910	4.10	16.77
PSS-8_2027 CHARGING PANLE-A	0.25	0.480	3.312	3.002	0.326	0.322	4.520	3.19	12.97
PSS-9_2027 CHARGING PANLE-A	0.25	0.525	3.648	3.304	0.357	0.343	4.975	3.50	14.21
PSS-10_2027 CHARGING PANLE-A	0.25	0.371	2.583	2.351	0.258	0.250	3.531	2.51	10.15

Below is the **harmonic current distortion** report after analysing the impact at the PSS and its nearby network at the Poonawala feeder. The study indicates scenario indicates that the Total harmonic distortion lies between 1.5 - 2.16%.

Table 2-27: Current harmonic distortion analysis impact in 2027 scenario

Device Number	Device Type	Fund. Current (A)	150.00 Hz IHD (%)	250.00 Hz IHD (%)	350.00 Hz IHD (%)	450.00 Hz IHD (%)	550.00 Hz IHD (%)	THD (%)	KIT (kA)	ITIF	PCC	I_{sc}/I_L	TDD (%)
PSS_TFR_1-A	Two-Winding Transformer	37.81	0.700	1.733	0.115	0.269	0.103	1.895	0.13	3.45	PSS_TFR_1-A	2065.07	1.895
PSS_TFR_2-A	Two-Winding Transformer	42.38	0.617	1.537	0.102	0.241	0.094	1.679	0.13	3.09	PSS_TFR_2-A	1842.28	1.679
PSS_TFR_3-A	Two-Winding Transformer	43.34	0.602	1.501	0.099	0.235	0.092	1.639	0.13	3.02	PSS_TFR_3-A	1801.73	1.639
PSS_TFR_4-A	Two-Winding Transformer	39.41	0.614	1.534	0.102	0.241	0.095	1.676	0.12	3.09	PSS_TFR_4-A	1981.15	1.676
PSS_TFR_5-A	Two-Winding Transformer	31.28	0.457	1.150	0.079	0.187	0.102	1.259	0.08	2.59	PSS_TFR_5-A	2496.26	1.259
PSS_TFR_2024_6-A	Two-Winding Transformer	29.37	0.488	1.231	0.085	0.202	0.111	1.346	0.08	2.79	PSS_TFR_2024_6-A	2530.18	1.346
PSS_TFR_2024_7-A	Two-Winding Transformer	40.19	0.601	1.507	0.102	0.241	0.104	1.647	0.13	3.13	PSS_TFR_2024_7-A	1848.81	1.647
PSS_TFR_2027_8-A	Two-Winding Transformer	28.58	0.641	1.624	0.111	0.268	0.127	1.774	0.10	3.51	PSS_TFR_2027_8-A	2537.08	1.774
PSS_TFR_2027_9-A	Two-Winding Transformer	26.13	0.785	1.978	0.134	0.325	0.135	2.161	0.11	4.11	PSS_TFR_2027_9-A	2709.79	2.161
PSS_TFR_2027_10-A	Two-Winding Transformer	20.53	0.701	1.777	0.122	0.295	0.131	1.941	0.08	3.79	PSS_TFR_2027_10-A	3618.86	1.941

The results monitored at PSS charging panel presented in the below figures.

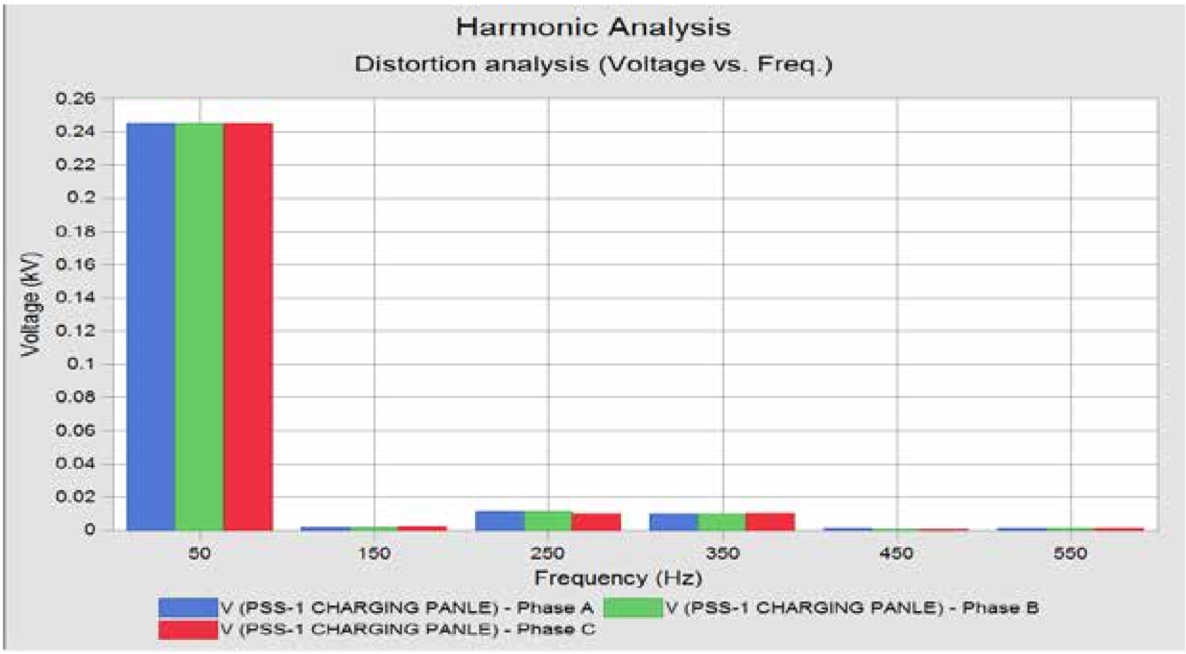


Figure 2-42: Voltage distortion at PSS connected to EVSE in 2027 scenario

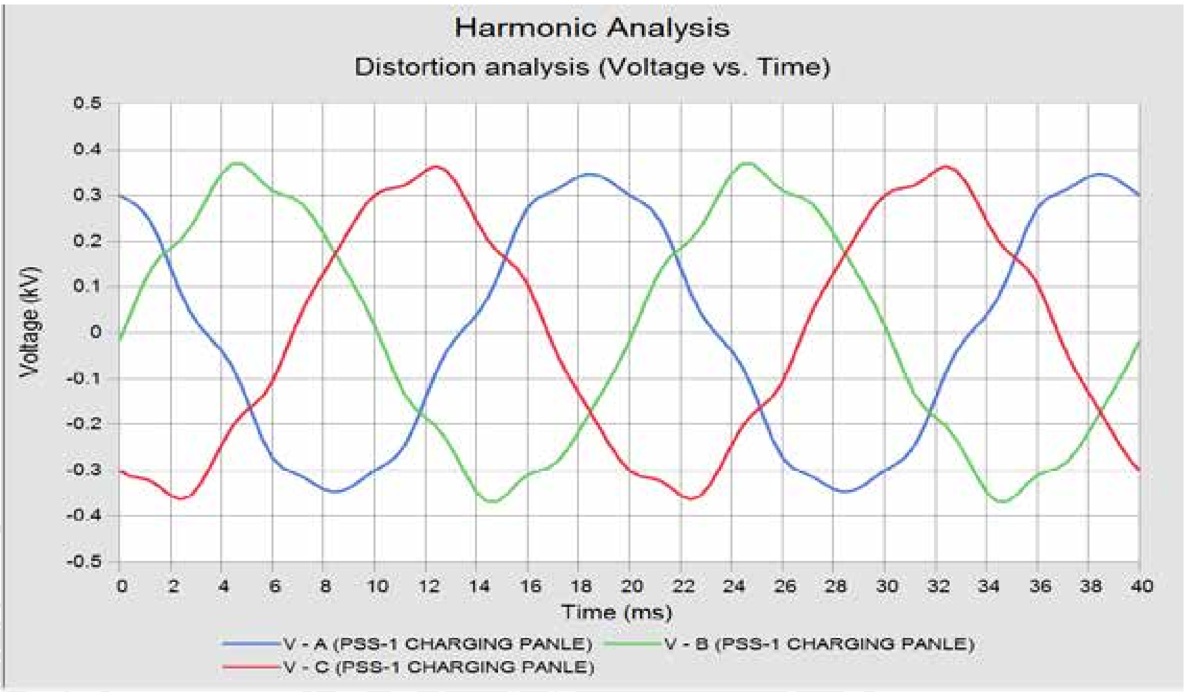


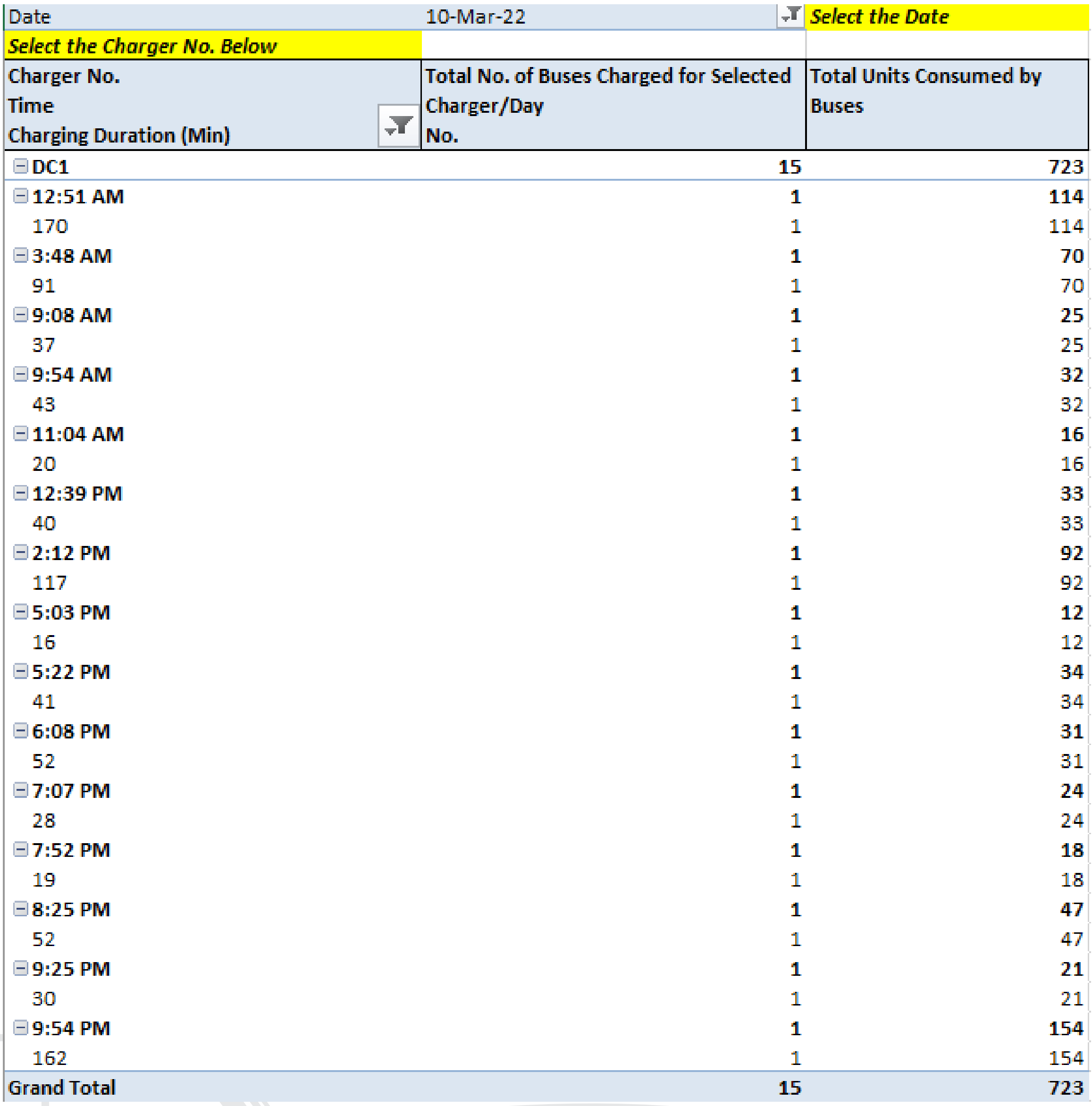
Figure 2-43: Voltage distortion at PSS connected to EVSE in 2027 scenario

Referring to the results in above Figures, it has been observed that the voltage distortions are within the limit for 5th and 7th order frequencies on the LT side of the PSS in time domain and frequency domain are acceptable as per IEEE 519 limits.

2.6 PMPML Log Book of Charging Session for March 2022

PMPML maintains a log book in which charging sessions of all the electric buses are recorded every day manually. We have analysed the log book for the month of March 2022. The details of the charging sessions of 150 kW DC charger on 10th March 2022 are given in the below table.

Table 2-28: Charging pattern DC charger no. DC1 of 150 kW



Date	10-Mar-22	*Select the Date*
Select the Charger No. Below		
Charger No. Time Charging Duration (Min)	**Total No. of Buses Charged for Selected Charger/Day No.**	**Total Units Consumed by Buses**
DC1	**15**	**723**
12:51 AM	**1**	**114**
170	1	114
3:48 AM	**1**	**70**
91	1	70
9:08 AM	**1**	**25**
37	1	25
9:54 AM	**1**	**32**
43	1	32
11:04 AM	**1**	**16**
20	1	16
12:39 PM	**1**	**33**
40	1	33
2:12 PM	**1**	**92**
117	1	92
5:03 PM	**1**	**12**
16	1	12
5:22 PM	**1**	**34**
41	1	34
6:08 PM	**1**	**31**
52	1	31
7:07 PM	**1**	**24**
28	1	24
7:52 PM	**1**	**18**
19	1	18
8:25 PM	**1**	**47**
52	1	47
9:25 PM	**1**	**21**
30	1	21
9:54 PM	**1**	**154**
162	1	154
Grand Total	15	723

As per the events recorded by PQ meter, on 10th March 2022 at 9:35 AM, there was an event of short interruption for 2 min 12 sec. This event did not have any major impact on the charging operations. Since, the log book is maintained manually for 58 AC chargers and 5 DC chargers and the readings recorded in the log book do not have the time stamps, the total charging load at any particular interval on a day is difficult to estimate. Hence, it was not technically feasible to model any actual charging scenario on the load flow model.

2.7 Conclusions from the Load-flow Studies

The load-flow results of the 2022 scenarios and the PQM measurements have been compared and found to be in alignment[8]. The scenarios studied for 2024 and 2027 assumed additional EVSE load besides normal load growth; and found voltage sags and harmonics beyond the acceptable limits. However, the EVSE load growth assumed for 2024 and 2027 could not be verified by relevant stakeholders. Hence, we did not estimate the mitigation measures in the absence of any accurate load growth estimates.

It is advised that when the EVSE load is enhanced in the bus depot, detailed planning studies may be undertaken to estimate the type and sizing of harmonic filters to be installed.

---

[8] Since the logbook maintained at the bus depot has manual entries without exact time stamps, it was difficult to model an exact charging scenario to conduct the load-flow

03

Power Quality Measurement Studies at Lake Depot in Kolkata

3.1 EVSE Installed in Kolkata Bus Depot

Lake Depot is one of the bus depots of the West Bengal Transport Corporation (WBTC) located in the southern part of Kolkata City. This depot has eight electric buses of 9-meter length (TATA make) which run on different city routes. To charge these buses, the depot has seven DC EVSEs – 6 x 60 kW and 1 x 120 kW (double gun). CESC Kolkata supplies power to this bus depot at 6 kV. There is a 500 kVA distribution transformer (6/0.43 kV) installed by CESC in this bus depot.

3.2 Power Quality Meter (PQM) Installed at Kolkata

ISGF with the help of CESC and Solvina has installed a Power Quality Meter of Metrum make (PQX3-FR) for recording and assessment of power quality in Lake depot. Metrum's PQX3-FR instrument is both a full feature fault recorder, and a high frequency measurement tool for power quality. The instrument is equipped with multiple current channels, allowing measurement on several different feeders simultaneously.

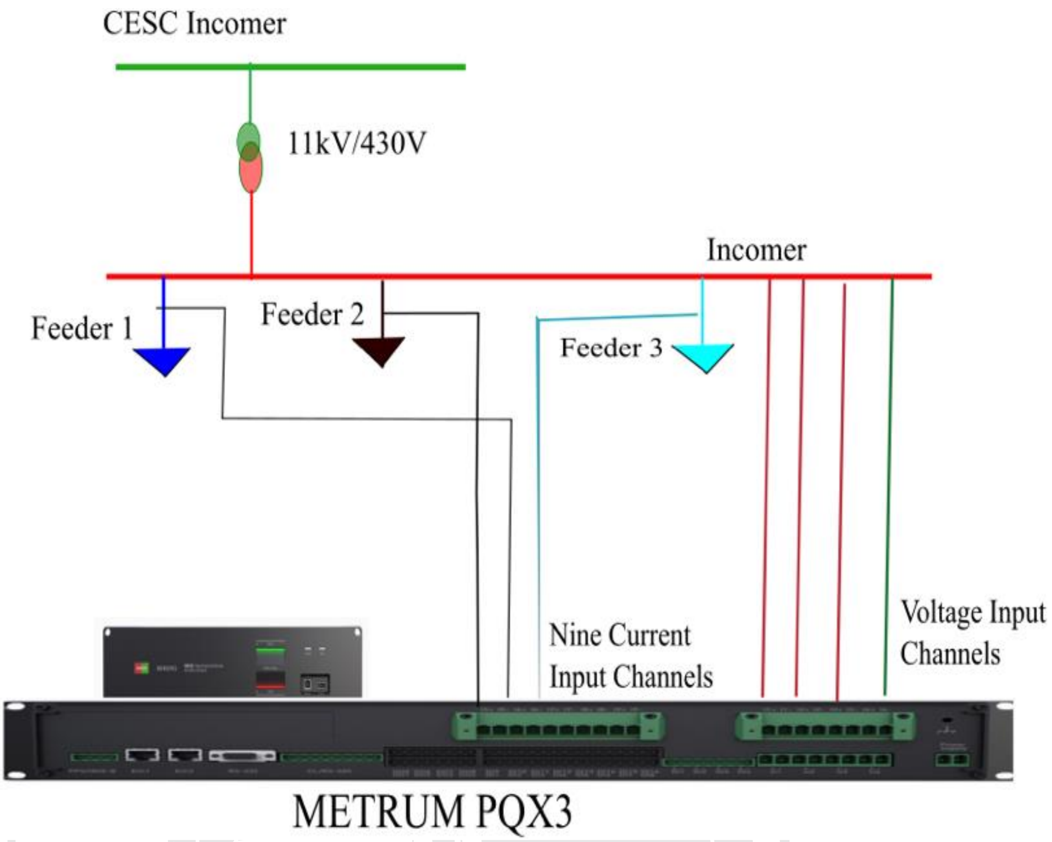


Figure 3-1: Power quality meter installed at Lake Bus Depot, Kolkata

Figure 3-2: PQX3 FR

The datasheet of PQM is attached at Appendix IV.

3.3 PQM Connection Diagram

The PQM has been installed on the LT side of the distribution transformer installed at Lake Depot, Kolkata. The connectivity of the PQM is given below:

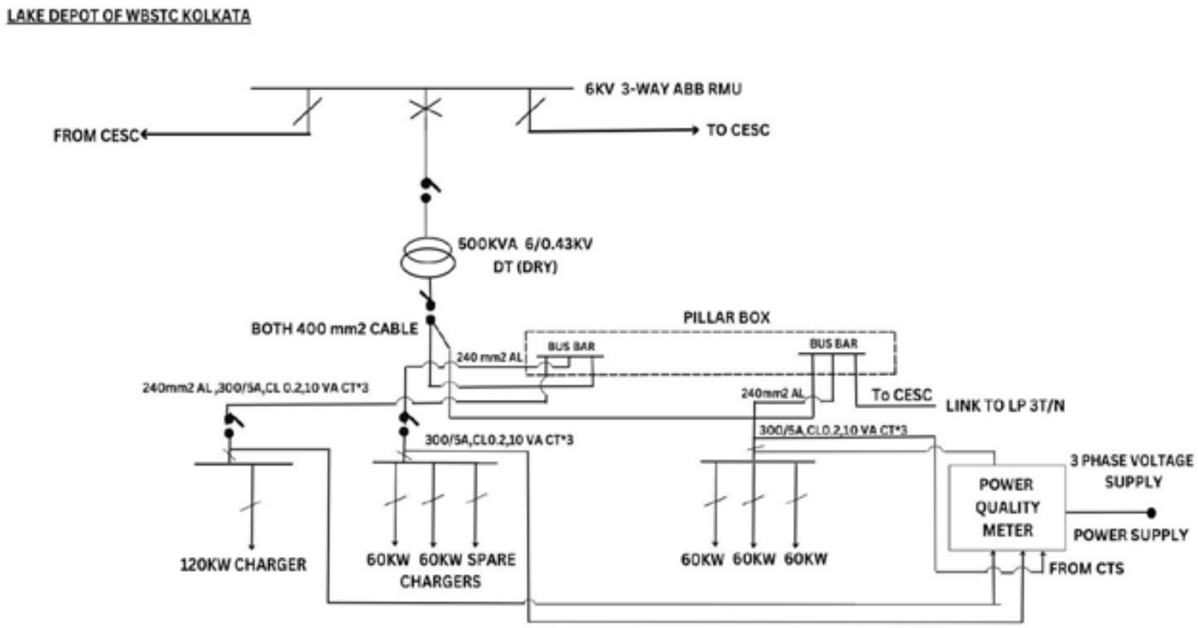


Figure 3-3: Connection diagram of PQM installed at Lake depot, Kolkata

- The installation has been provided with a 500 kVA 6/0.43 kV dry type distribution transformer by CESC
- Two 400 SqMM aluminium cable have been terminated to the secondary (0.43 kV) side of the transformer, the other side of the cables are connected to two separate bus bars inside a Pillar Box, adjacent to the DT
- From Bus bar Pillar Box-1, two 240 SqMM cables are connected to two separate CT metered supply (1 and 2) to WBTC, inside a meter room which is close to pillar box
- A third cable of 240 SqMM from bus bar pillar box-2 is connected to the third CT metered supply (3) to WBTC in the meter room
- Single cables from the three metered supply, through proper switch fuse units are terminated to local LT panel in charging area

- Unit 1 is connected to a 120 kW charger and unit 2 and 3 are connected to 3 x 60 kW chargers through proper isolation and protection arrangements

Figure 3-4: Meter room at Lake bus depot, Kolkata – PQM installed

- In order to measure/monitor the power quality at LT metering points, the PQM has been installed in the meter room. The input to the PQM is provided through current transformers (CTs) (300/5 A, Class 0.2, 10 VA) installed on all three phases of the three different circuits going to the EVSEs. CTs have been inserted on single core cables between CESC fuse units and the main switch adjacent to meter box.

3.4 PQM Measurement and Observations

For power quality measurement and analysis, the 3 LT connections of 230 V were connected to the PQM (PQX3-FR) through Current Transformers (CTs).

Brief descriptions about voltage sags, transients, flicker, voltage variations, harmonics, SEMI F47 etc. are given in Chapter 2 hence those are not being repeated here.

3.4.1 Voltage Sag

Figures below shows the recorded voltage sag of 40% of Unom (nominal voltage) at Lake depot for the month of October 2021 in Phase 1.

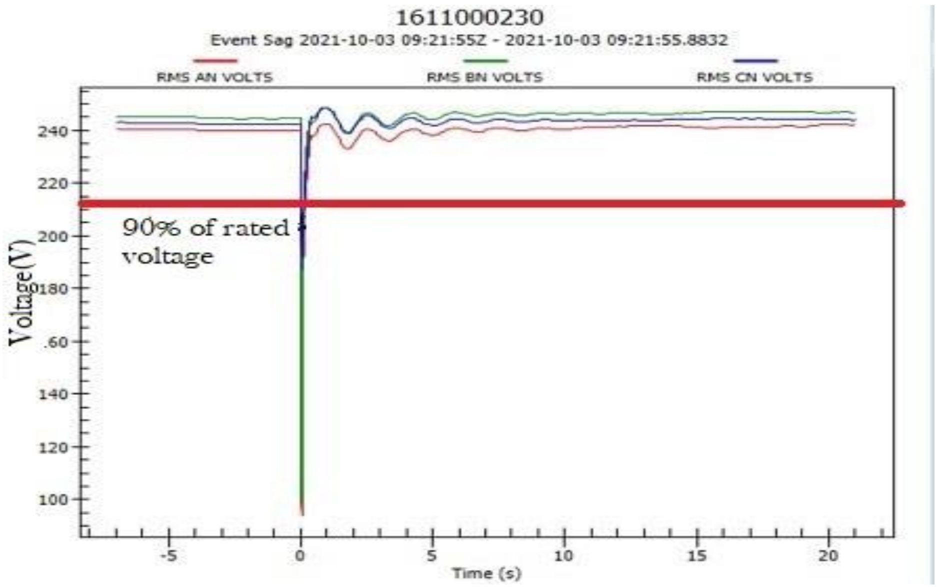


Figure 3-5: Voltage sag at Lake depot - 40% of Unom phase 1

The above figure depicts the voltage sag from the rated voltage of 230 V to 40% (92 V) whereas the threshold limit is 90% of rated voltage (230 V) which is 207 V.

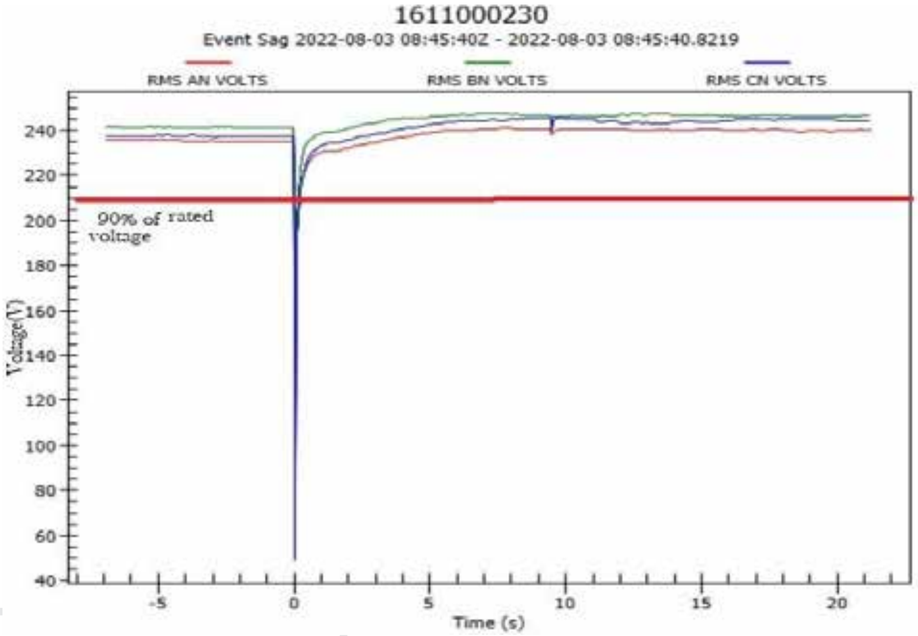


Figure 3-6: Voltage sag at Lake bus depot - 21% of Unom phase 1

The above figure depicts the voltage sag of 21% of Unom recorded on 03 August 2022 at Lake depot.

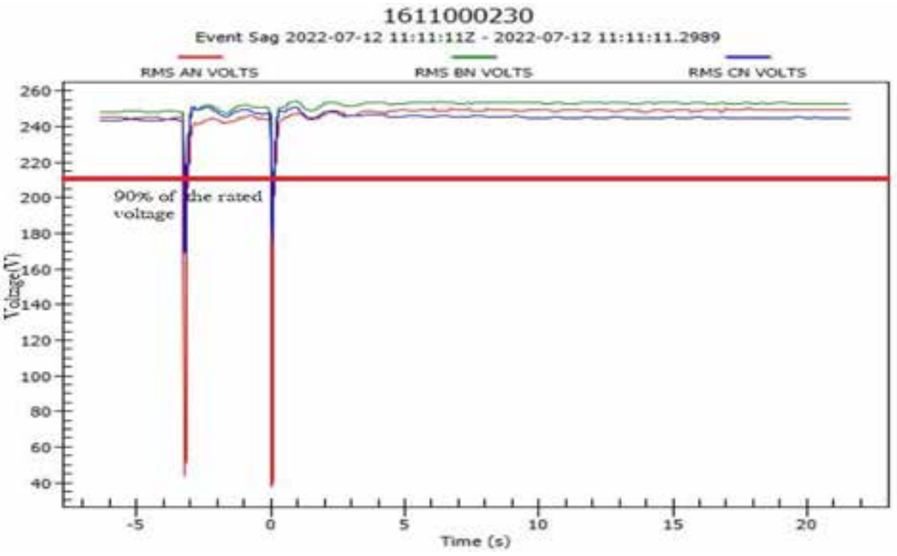


Figure 3-7: Voltage sag at Lake bus depot - 15% of Unom phase 1

The above figure depicts the voltage sag of 15% of Unom recorded on 12 July 2022 at Lake depot.

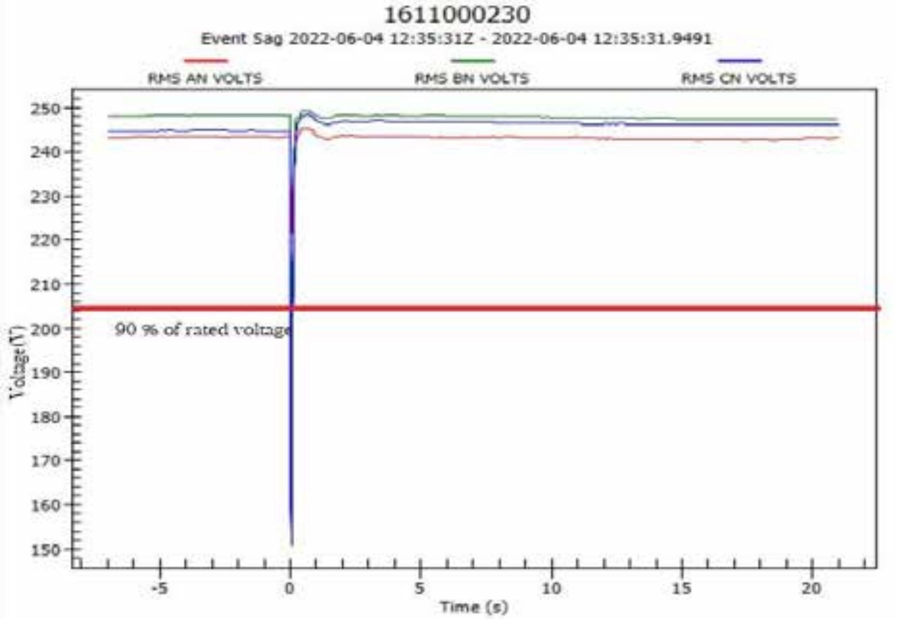


Figure 3-8: Voltage sag at Lake bus depot - 62% of Unom phase 3

The above figure depicts the voltage sag of 62% of Unom recorded on 04 June 2022 at Lake depot.

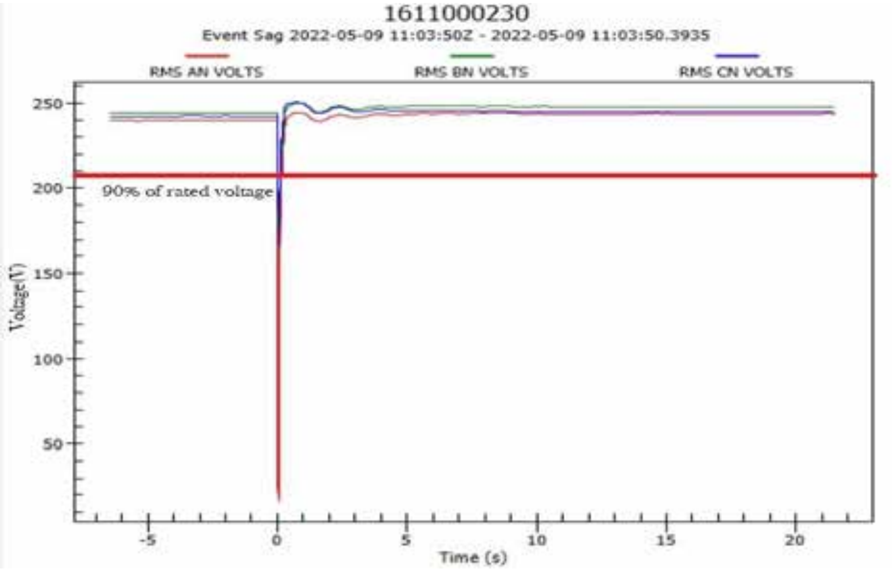


Figure 3-9: Voltage sag at Lake bus depot - 7% of Unom phase 1

The above figure depicts the voltage sag of 7% of Unom recorded on 09 May 2022 at Lake depot.

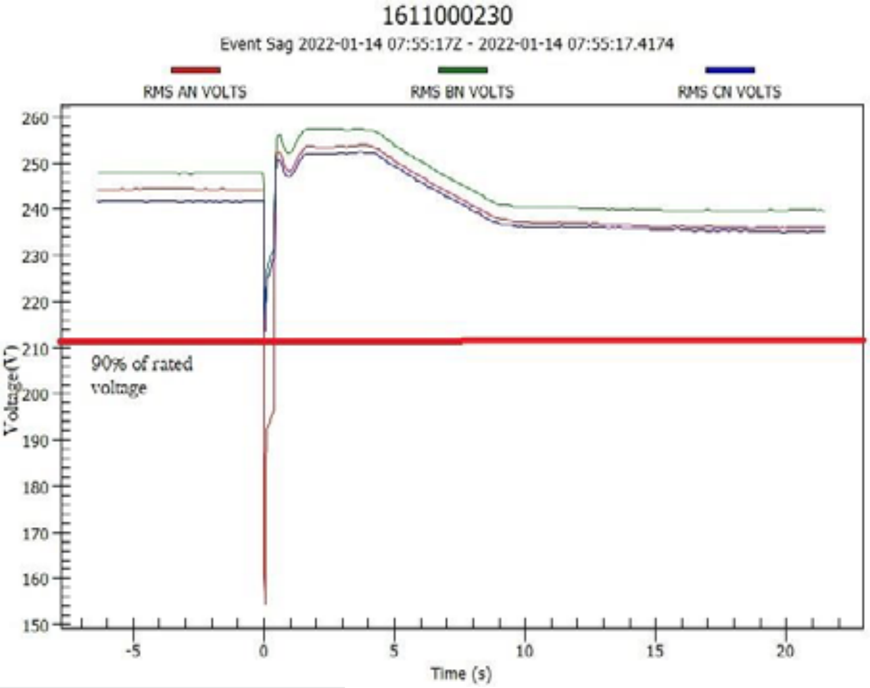


Figure 3-10: Voltage sag at Lake bus depot - 63% of Unom phase 1

The above figure depicts the voltage sag of 63% of Unom recorded on 14 January 2022 at Lake depot.

The below table shows the recorded voltage sag of ≤ 60 % from December 2021 to August 20222 except for the February 2022 and March 2022 where no voltage sag of ≤60% were recorded.

Table 3-1: List of sags less than 60% of Unom recorded at Lake depot, Kolkata

Sl No	Time	Voltage	% Of Unom	Direction
1	02-12-2021	100.51	41.136684	Upstream
2	02-12-2021	109.47	44.718426	Upstream
3	02-12-2021	145.70	60.333969	Upstream
4	24-04-2022	93.798	39.142948	Upstream
5	24-04-2022	117.93	49.383655	Upstream
6	01-05-2022	130.79	55.320732	Upstream
7	01-05-2022	134.07	55.425243	Upstream
8	01-05-2022	134.08	56.498737	Upstream
9	09-05-2022	16.253	6.8168334	Upstream
10	12-05-2022	111.93	47.662288	Upstream
11	12-05-2022	113.48	47.889541	Upstream
12	12-05-2022	119.92	49.689037	Upstream
13	12-05-2022	115.19	48.624557	Upstream
14	12-05-2022	127.90	53.896690	Upstream
15	12-05-2022	130.97	54.396713	Upstream
16	04-06-2022	150.66	60.683601	Upstream
17	12-07-2022	43.806	17.902435	Upstream
18	12-07-2022	37.401	15.287155	Upstream
19	17-07-2022	86.645	35.571647	Upstream
20	17-07-2022	92.753	37.390907	Upstream
21	22-07-2022	106.85	44.862171	Upstream
22	03-08-2022	49.601	21.079986	Upstream
23	03-08-2022	49.074	20.676002	Upstream
24	03-08-2022	52.889	21.947425	Upstream
25	08-08-2022	103.06	42.923549	Upstream
26	08-08-2022	92.050	37.399818	Upstream
27	09-08-2022	102.03	43.192146	Upstream
28	09-08-2022	99.708	41.340290	Upstream

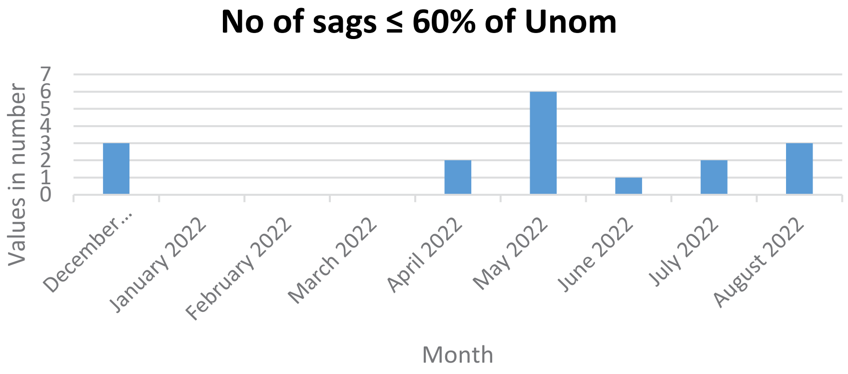


Figure 3-11: Voltage sags

The above figure shows the voltage sags of 60% or less from December 2021 to August 2022. For the month of January 2022, February 2022, March 2022, no sag ≤ 60% were recorded.

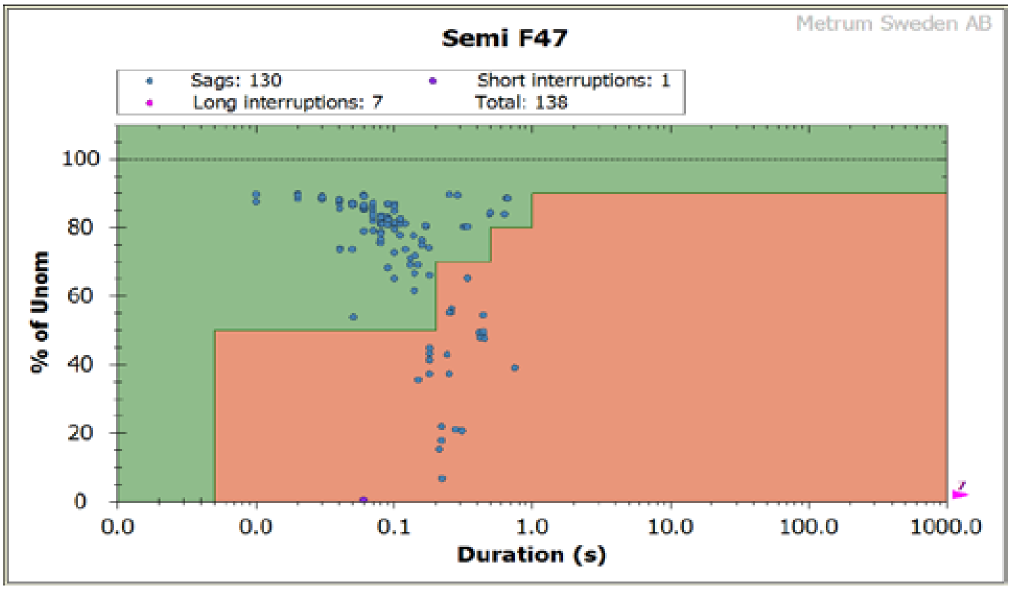


Figure 3-12: Recorded voltage sags at Lake bus depot as per Semi F47

Semi F47 is semiconductor processing equipment voltage sag immunity standard which explains the severity of sags with respect to its effect on semiconductor devices. The above figure depicts a total 130 sags recorded during the span of one year where 28 sags are in the brown area having potential to damage the semiconductor devices connected to the network.

3.4.2 Rapid Voltage Changes (RVC)

A rapid change in the voltage faster than the 0.5 percent per second, where the effective voltage value before, during and after the change is between 90 percent and 110 percent of the reference voltage. The stationary and maximum voltage change determines rapid voltage changes where ΔU stationary is the difference between the effective voltage value before and after the change and ΔUmax is the maximum voltage change during a voltage change course.

Table 3-2- RVC limits as per standard

Rapid voltage changes (RVC)	Maximum number per day	
	Un ≤ 45 kV	Un > 45 kV
$\Delta U_{stationary} \geq 3\%$	24	12
$\Delta U_{max} \geq 5\%$	24	12

RVC exposure to electronic equipment can produce corrupted results while converters may run at varying loads. Below graphs depicts the events of RVC recorded at Lake depot, Kolkata.

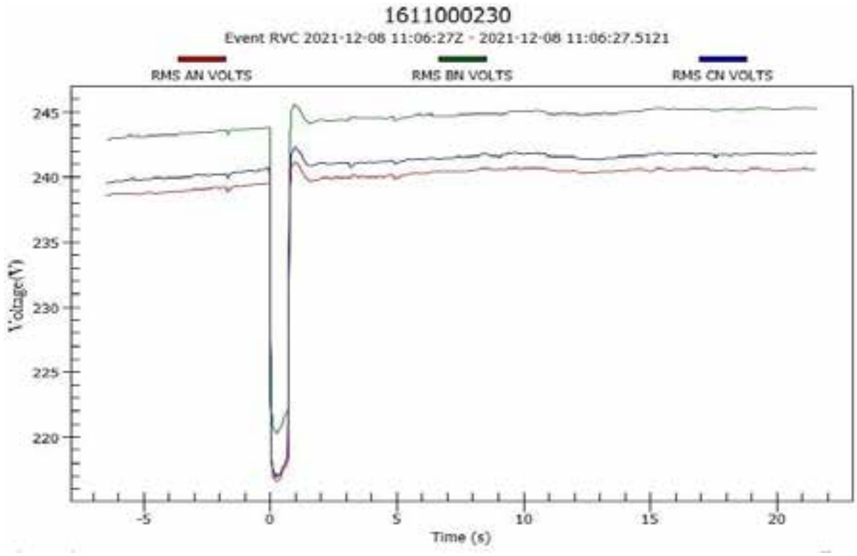


Figure 3-13: RVC recorded for 1.46 seconds for phase 1 on 08 December 2021

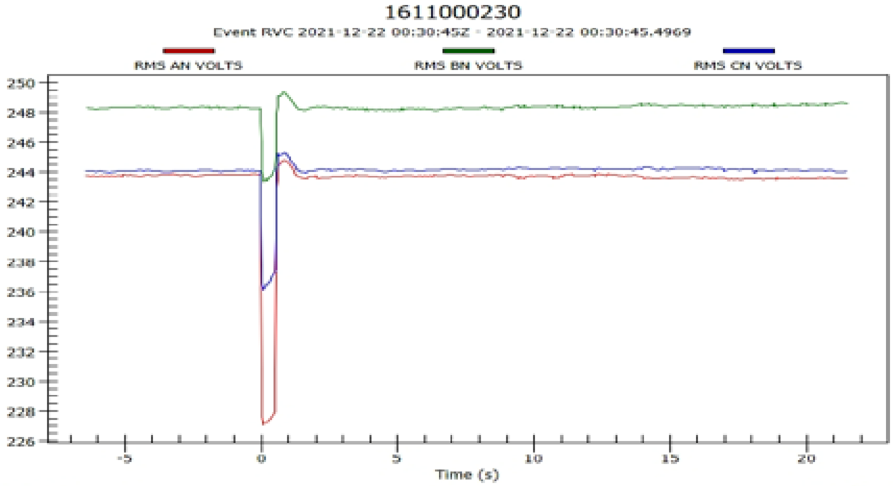


Figure 3-14: RVC recorded for 1.18 seconds for phase 1 on 22 December 2021

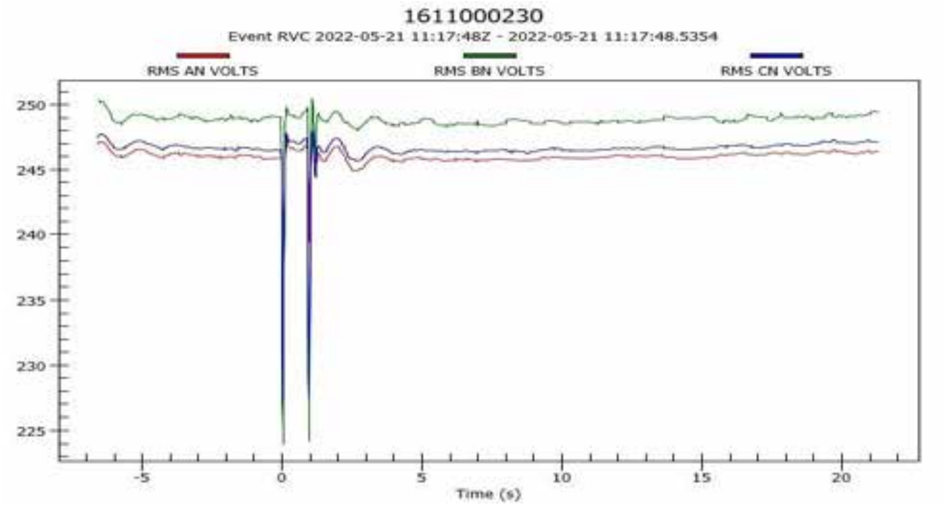


Figure 3-15: RVC recorded for 1 seconds for phase 3 on 05 May 2022

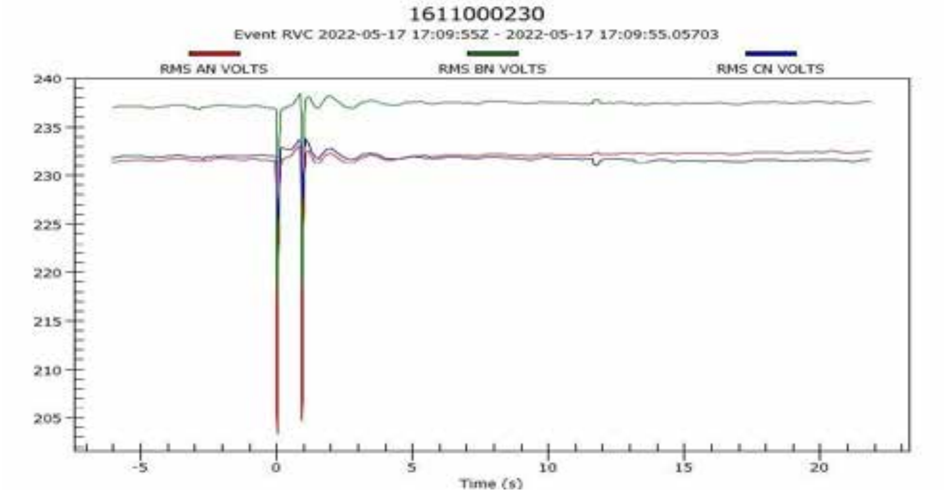


Figure 3-16: RVC recorded for 0.98 seconds for phase 2 on 17 May 2022

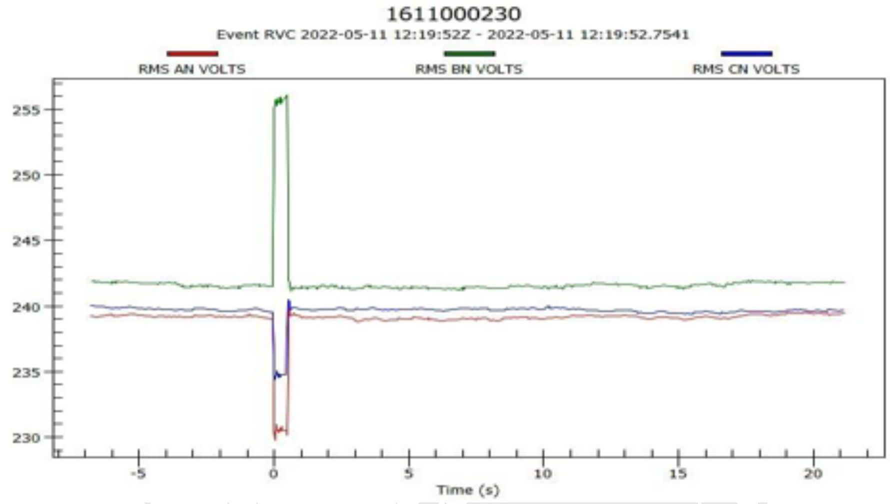


Figure 3-17: RVC recorded for 1.11 seconds for phase 2 on 11 May 2022

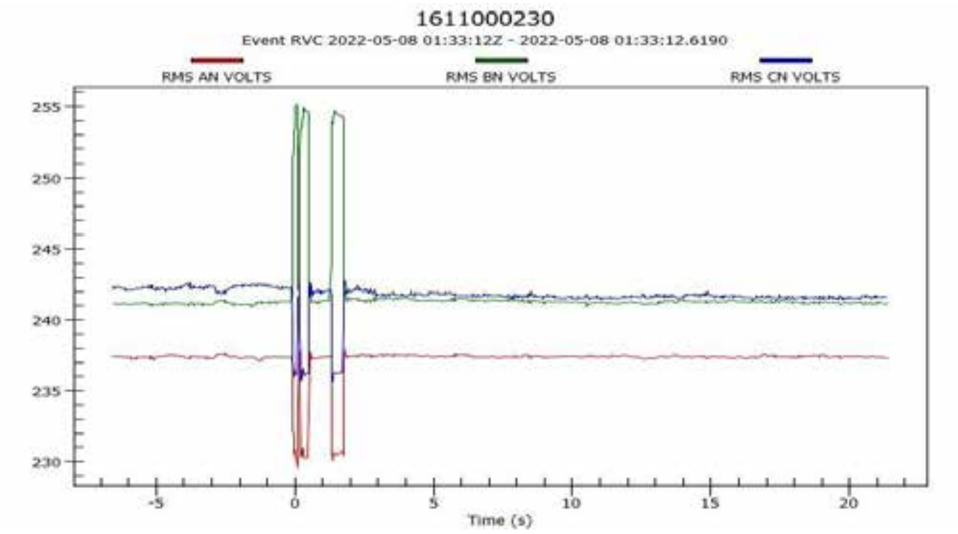


Figure 3-18: RVC recorded for 2.31 seconds for phase 2 on 08 May 2022

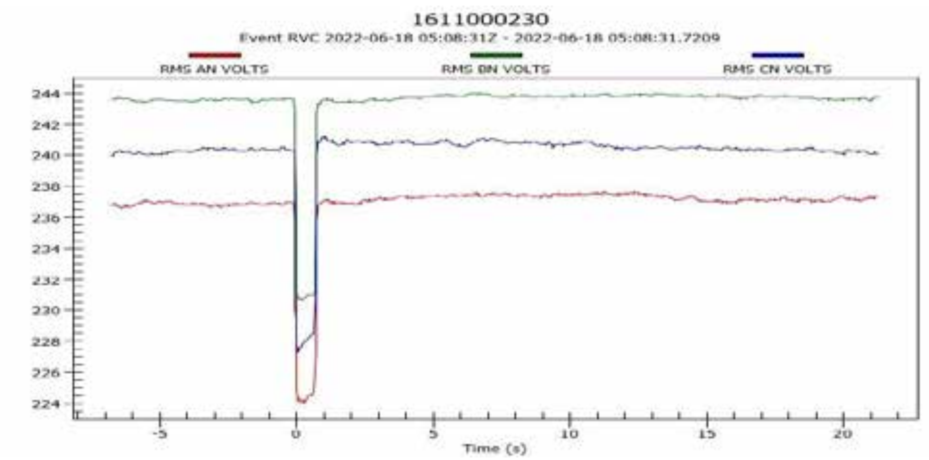


Figure 3-19: RVC recorded for 1.24 seconds for phase 1 on 18 June 2022

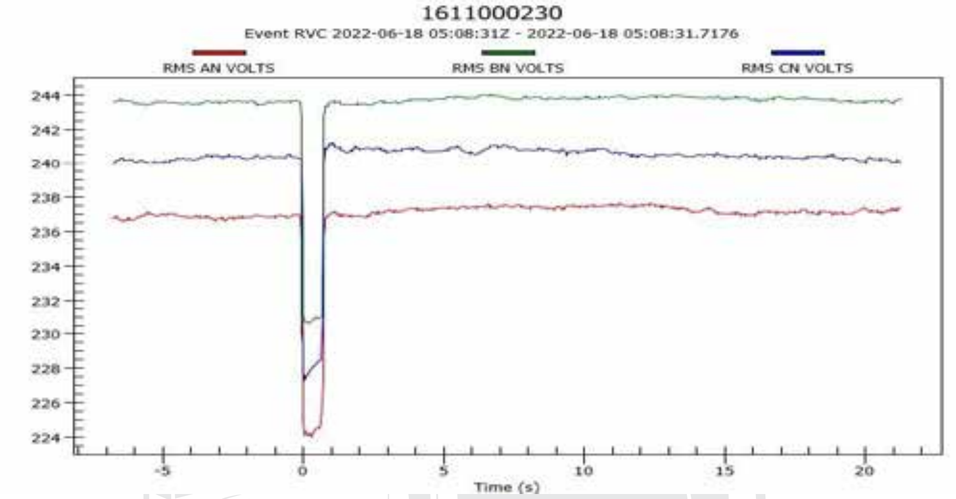


Figure 3-20: RVC recorded for 1.25 seconds for phase 2 on 18 June 2022

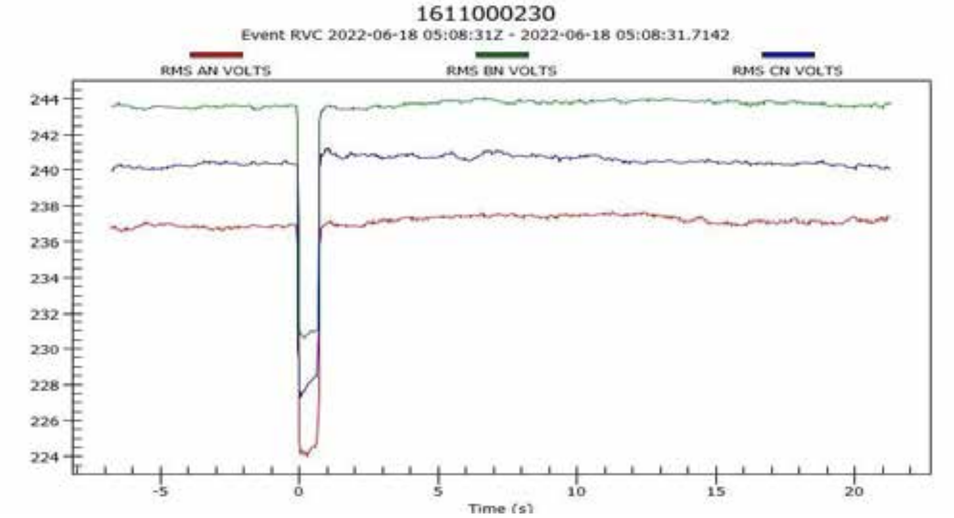


Figure 3-21: RVC recorded for 1.26 seconds for phase 3 on 18 June 2022

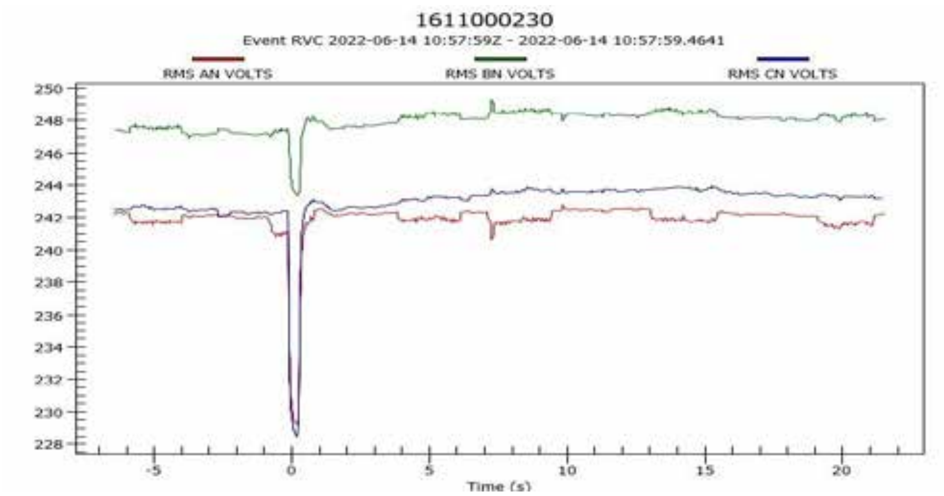


Figure 3-22: RVC recorded for 0.87 seconds for phase 3 on 14 June 2022

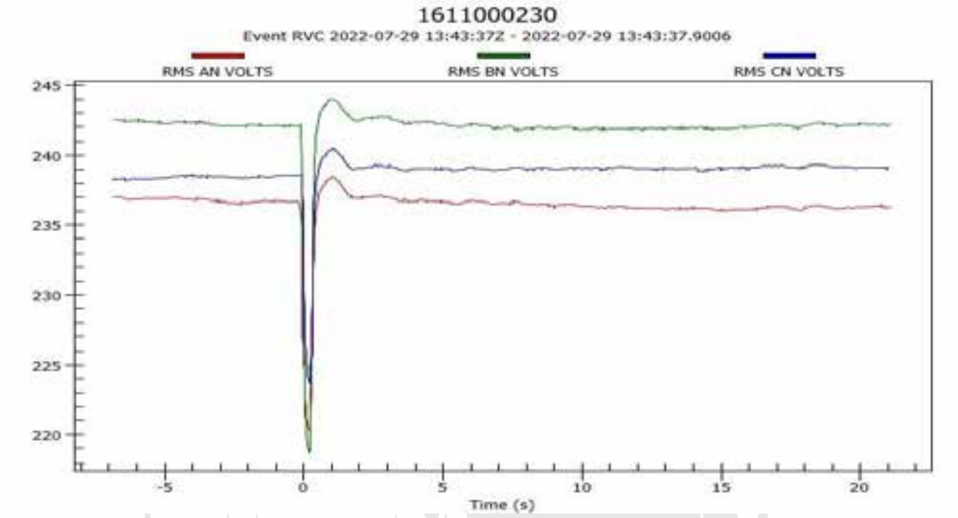


Figure 3-23: RVC recorded for 1.1 seconds for phase 2 on 29 July 2022

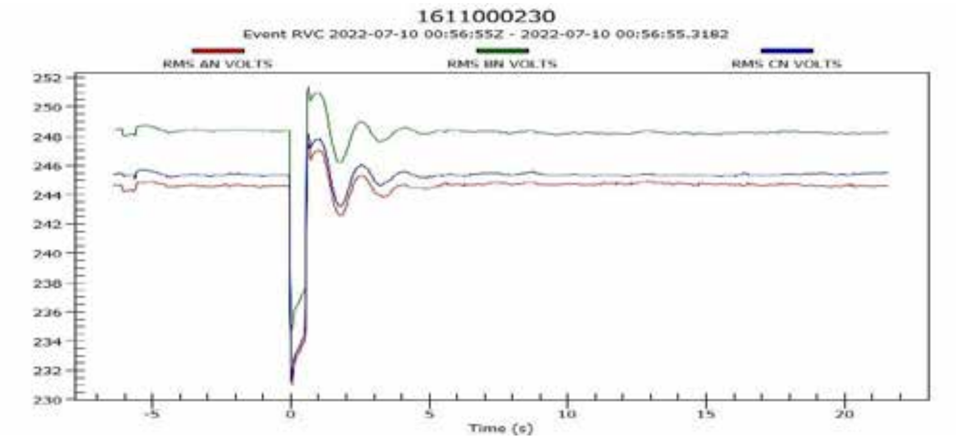


Figure 3-24: RVC recorded for 1.13 seconds for phase 1 on 10 July 2022

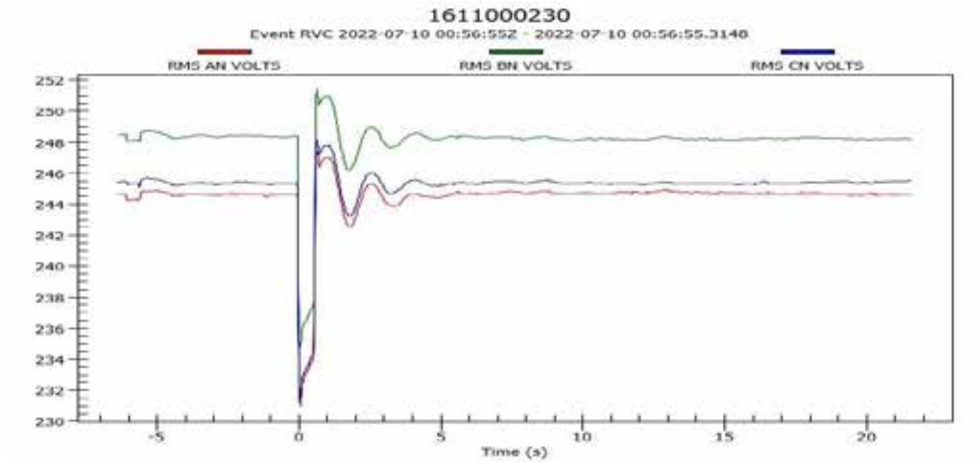


Figure 3-25: RVC recorded for 1.14 seconds for phase 2 on 10 July 2022

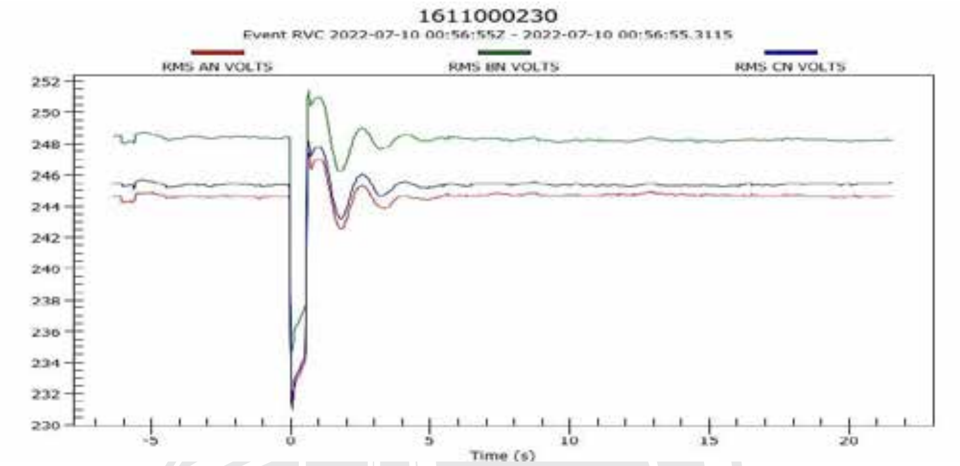


Figure 3-26: RVC recorded for 1.14 seconds for phase 3 on 10 July 2022

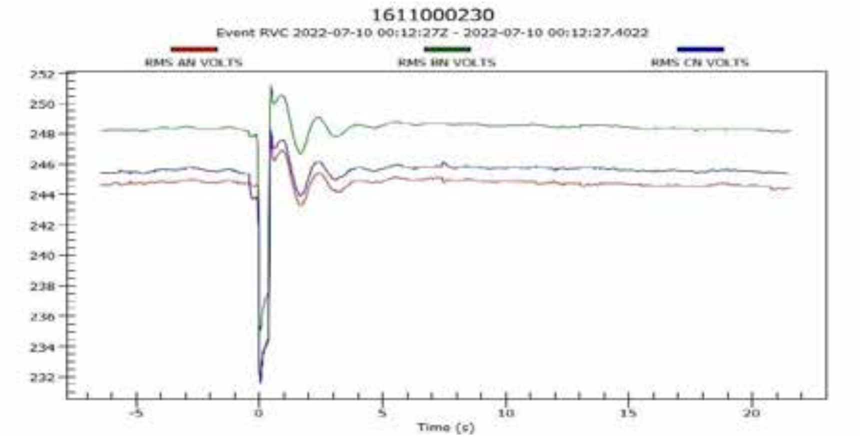


Figure 3-27: RVC recorded for 1 seconds for phase 3 on 10 July 2022

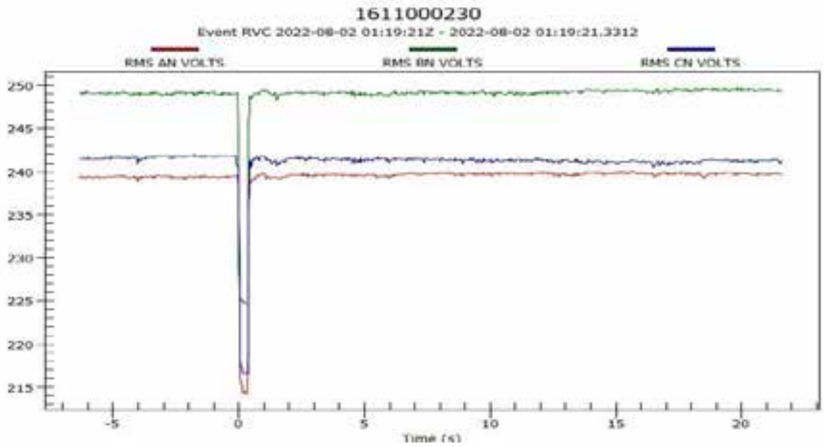


Figure 3-28: RVC recorded for 1.15 seconds for phase 2 on 02 August 2022

Table 3-3: List of Rapid Voltage Changes recorded at Lake depot, Kolkata

Sl No	Time	Duration	Voltage
1	08-12-2021	1.4615	245.58
2	22-12-2021	1.1003	242.51
3	22-12-2021	1.1803	244.85
4	01-01-2022	1.1184	242.26
5	01-01-2022	1.1085	243.05
6	01-01-2022	1.1084	244.83
7	08-05-2022	2.3171	255.14
8	11-05-2022	1.1104	256.06
9	17-05-2022	0.9843	238.34
10	21-05-2022	1.0080	248.11
11	14-06-2022	0.8791	243.12
12	18-06-2022	1.2436	237.16

13	18-06-2022	1.2536	243.66
14	18-06-2022	1.2637	241.19
15	10-07-2022	1.009	248.17
16	10-07-2022	1.1307	247.44
17	10-07-2022	1.1408	251.36
18	10-07-2022	1.1408	248.13
19	29-07-2022	1.1099	244.05
20	02-08-2022	1.1597	249.52

The above Table shows the deviated voltage from 230 V from the month of December 2021 to August 2022 except February 2022, March 2022 and April 2022 as no voltage deviation were recorded.

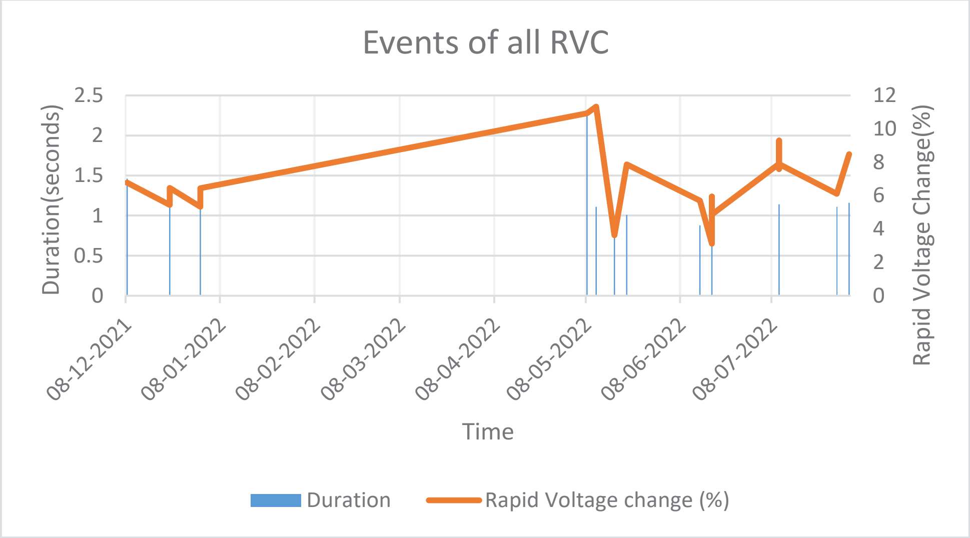


Figure 3-29: Events of RVC from December 2021 to August 2022

As per EN50160 (acceptable limit is 5 % of voltage change), Rapid Voltage Change (RVC) is above the acceptable limit as shown in the above figure, hence the study failed in the RVC parameter from December 2021 to August 2022 except for the month of May and June 2022.

3.4.3 Flicker

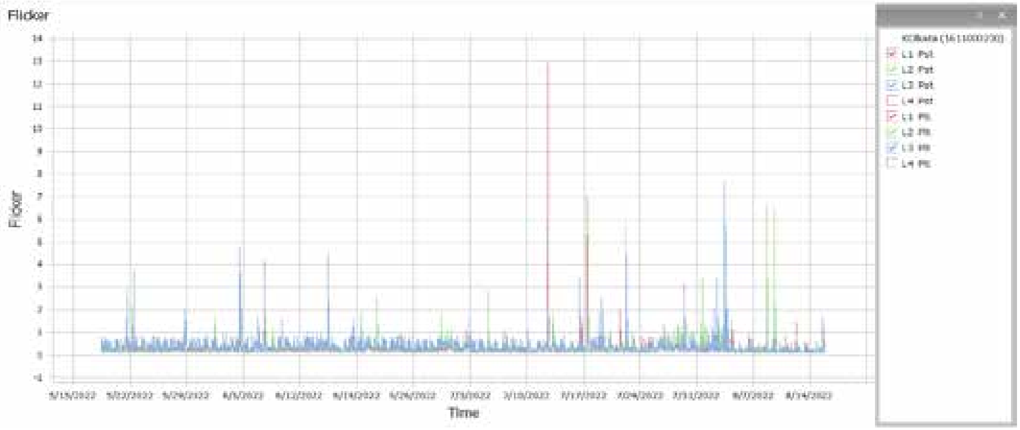


Figure 3-30: Flicker recorded at Lake bus depot

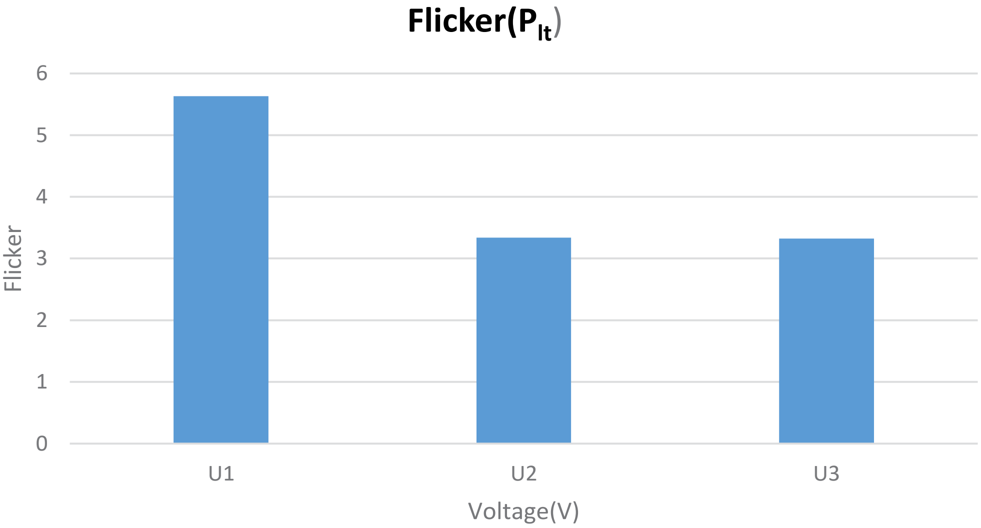


Figure 3-31: Flicker recorded (Plt)

The flicker recorded are with in the limits (1pu) set by EN50160. As per EN50160 the allowable limit is 1 for 95% of the time.

3.4.4 Voltage

The below Figure depicts recorded voltage (RMS values) sampled at every minute at Lake depot, Kolkata.

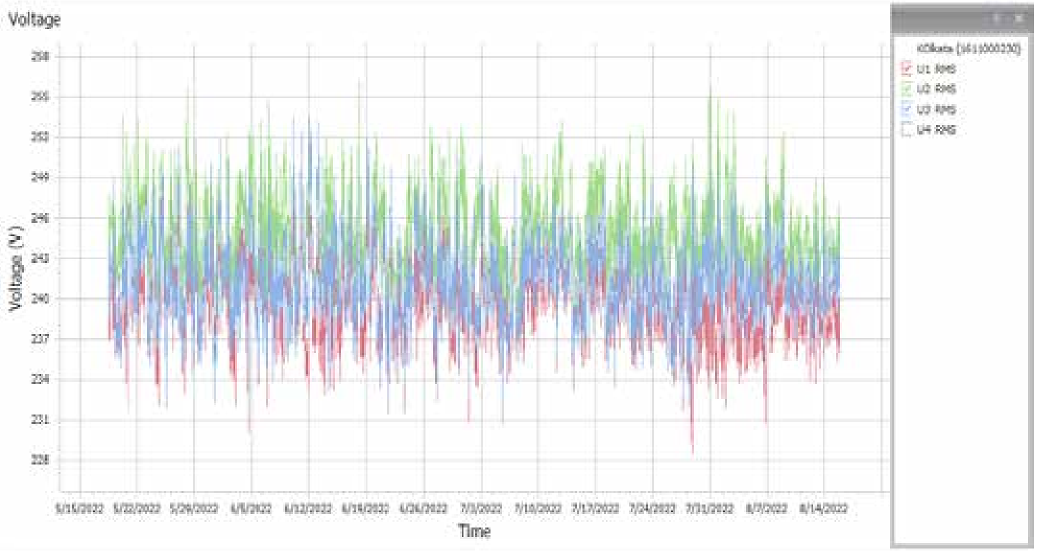


Figure 3-32: Voltage recorded at Lake depot, Kolkata

3.4.5 Current

The below Figure depicts recorded current (RMS values) sampled at every minute at Lake depot, Kolkata.

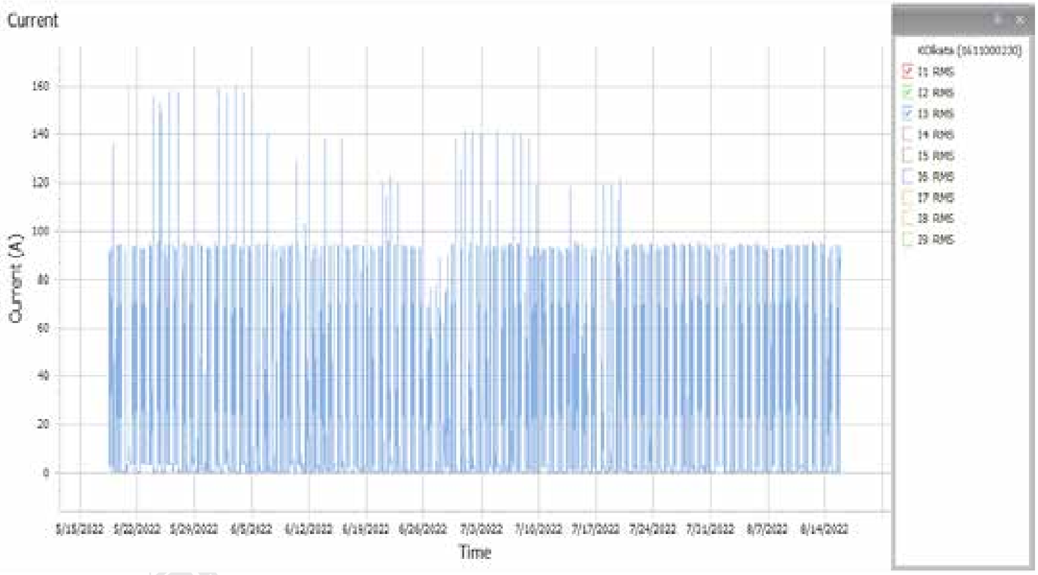


Figure 3-33: Current recorded at Lake depot, Kolkata

3.4.6 Harmonics Recorded

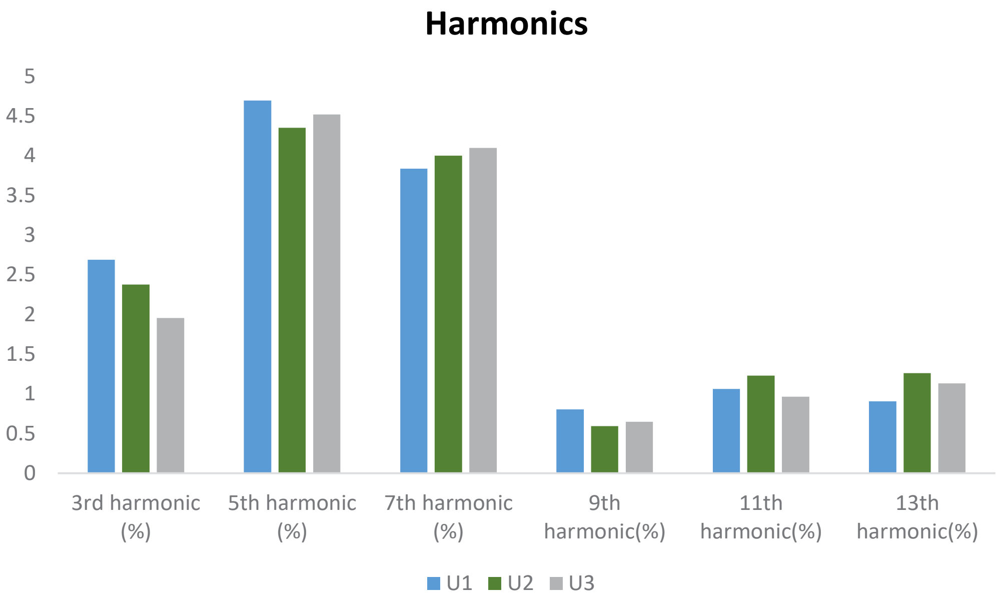


Figure 3-34: Harmonics (%) recorded at Lake depot, Kolkata

3.4.7 Voltage Variations

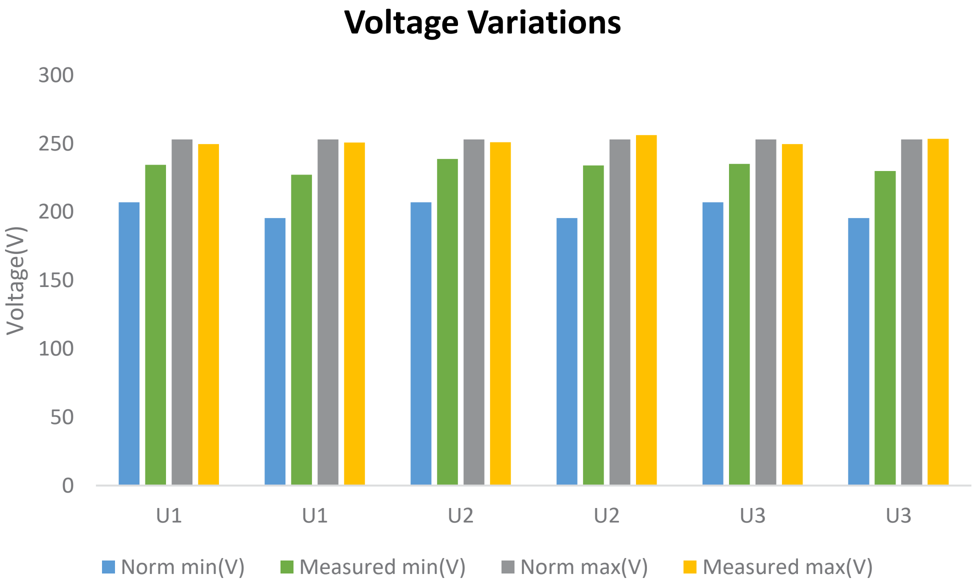


Figure 3-35: Voltage variations recorded from December 2021 to August 2022

3.4.8 Total Harmonic Distortion

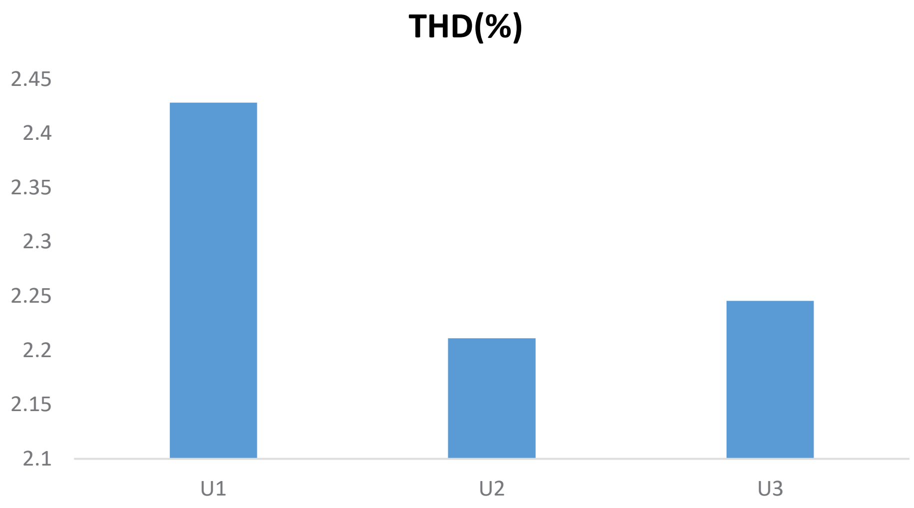


Figure 3-36: THD recorded at Lake bus depot

The THD recorded are within the limits (8%) set by EN50160.

3.4.9 Conclusion

The power quality monitoring study conducted at **Lake depot, Kolkata, for the time span of December 2021 to August 2022** concludes:

- The power quality standard **EN50160** is used for the PQ study and analysis
- The observed **RVCs** (Rapid Voltage Change) for complete span of time have failed according to EN50160. These RVSs have higher severity level and have the potential to damage electronic and semiconductor devices.
- As most problems are caused by intermittent reoccurring faults, it is important to look at power quality measurements from a not-too-distant measurement point that has been recording during the time the customer experienced the equipment failure. In the best case a voltage dip or rapid voltage change can be seen on such measurement, which can be correlated with the equipment failure.
- Reports generated for **Voltage Variations** as per EN50160 are Failed for the complete span of time. There is only load responsible for voltage variations.
- Reports generated for **THD** and **Individual Harmonics** as per EN50160 are Passed for the complete span of time
- Reports generated for **Voltage Unbalance** as per EN50160 are Passed for the complete span of time
- Reports generated for **Frequency and Signalling Voltage** as per EN50160 are Passed for the complete span of time
- All report generated for **Flicker (P_{lt})** as per EN50160 are Passed for the complete span of time
- The observed **Voltage Sags** for complete span of time are within the limits according to EN50160. However, during the one year of measurement, a total of 28 sags out of recorded 130 are below 60% of rated voltage. As per Semi F47, these sags are having higher severity level and have the

potential to damage electronic and semiconductor devices. These sags are being induced in the electrical networks from upstream. As most problems are caused by intermittent reoccurring faults (often voltage dips), it is important to look at power quality measurements from a not-too-distant measurement point that has been recording during the time the customer experienced the equipment failure. In the best case, a voltage dip or rapid voltage change can be seen on such measurement, which can be correlated with the equipment failure.

- It is recommended to install Class-A online power quality monitoring system to continuously monitor voltage sags so that correlation can be established in case of equipment/component failure
- The measured **THD** as per EN50160 for the complete span of time is within limits
- The load profile observed at the PQ measurement point is less than 50% of the total capacity, **however if the loading increases the power quality may degrade**
- It is recommended to have continuous online monitoring system and perform regular analysis for a longer period till the installed load increase to the planned load (maximum). It is also recommended to monitor the voltage variations very closely and if they are increasing with the course of time, some mitigation methods shall be adopted like installation of automatic tap changer controls.

3.5 Load Flow Study on the 6 kV Feeder and EVSE Network

The detailed impact study of the 6 kV Deodar feeder from Prince Anwar Shah distribution substation for EVSE installations at Lake Depot has been performed using CYME power system simulation software. The unbalanced three-phase load flow simulation and harmonic analysis have been conducted to study system performance for the impact of EVSE on the conventional electrical network. The Lake depot, Kolkata has seven DC EVSEs – 6 x 60 kW and 1 x 120 kW (double gun).

3.5.1 Load Flow Scenario

Below are the inputs considered to model the 6 kV Deodar feeder from Prince Anwar Shah distribution substation and the EVSE installed at Lake depot, Kolkata.

Table 3-4: List of two-winding transformers installed at Lake depot, Kolkata

Network Id	Equipment No	Equipment Id	Cap Nom (kVA)	Prim Volt (kV_{LL})	Sec Volt (kV_{LL})	No load loss (kW)
PRINCE ANWER SHAH-SS	PRINCE ANWER SHAH-SS P/T	33/6KV_16 MVA	16000.00	33.00	6.00	0.45
PRINCE ANWER SHAH-SS	PRINCE ANWER SHAH-SS P/T	33/6KV_16 MVA	16000.00	33.00	6.00	0.45
DEODAR_FDR	BAKTIAR SHAH RD P/T	6/0.433_315 kVA	315.00	6.00	0.43	0.60
DEODAR_FDR	231	6/0.433_315 kVA	315.00	6.00	0.43	0.60
DEODAR_FDR	LAKE GARDENS FLYOVER O/T NO.2	6/0.433_400 kVA	400.00	6.00	0.43	0.70
DEODAR_FDR	LAKE GARDENS FLYOVER O/T NO.1	6/0.433_315 kVA	315.00	6.00	0.43	0.60
DEODAR_FDR	196	6/0.433_315 kVA	315.00	6.00	0.43	0.60
DEODAR_FDR	ABB RMU DEODAR RAHAMAN (C) O/T	6/0.433_500 kVA	500.00	6.00	0.43	0.94

DEODAR_FDR	LAKE GARDENS (W) T/H	6/0.433_400 kVA	400.00	6.00	0.43	0.70
DEODAR_FDR	SULTAN ALAM RD O/T	6/0.433_400 kVA	400.00	6.00	0.43	0.70
DEODAR_FDR	CHARU CHANDRA PLACE (E) P/T	6/0.433_315 kVA	315.00	6.00	0.43	0.60
DEODAR_FDR	CHARU CHANDRA PLACE (N) P/T	6/0.433_400 kVA	400.00	6.00	0.43	0.70
DEODAR_FDR	RUSSA RD 1ST LN O/T	6/0.433_400 kVA	400.00	6.00	0.43	0.70

Table 3-5: List of chargers installed at Lake depot, Kolkata

Network Id	Charger Type	Nominal Power (kW)	Input Voltage (kV_{LL})	Output Voltage (V)	Efficiency (%)	Ctrl Type	Operating Voltage (V)	Operating PF (%)
ABB RMU DEODAR RAHAMAN (C) O/T	DEODAR-120 kW FAST CHARGER	150.0	0.4	720.0	95.0	Fixed Voltage	720.0	95.0
ABB RMU DEODAR RAHAMAN (C) O/T	DEODAR-60 kW SLOW CHARGER-1	100.0	0.4	720.0	95.0	Fixed Voltage	720.0	95.0
ABB RMU DEODAR RAHAMAN (C) O/T	DEODAR-60 kW SLOW CHARGER-2	100.0	0.4	720.0	95.0	Fixed Voltage	720.0	95.0
ABB RMU DEODAR RAHAMAN (C) O/T	DEODAR-60 kW SLOW CHARGER-3	100.0	0.4	720.0	95.0	Fixed Voltage	720.0	95.0
ABB RMU DEODAR RAHAMAN (C) O/T	DEODAR-60 kW SLOW CHARGER-4	100.0	0.4	720.0	95.0	Fixed Voltage	720.0	95.0
ABB RMU DEODAR RAHAMAN (C) O/T	DEODAR-60 kW SLOW CHARGER-5	100.0	0.4	720.0	95.0	Fixed Voltage	720.0	95.0
ABB RMU DEODAR RAHAMAN (C) O/T	DEODAR-60 kW SLOW CHARGER-6	100.0	0.4	720.0	95.0	Fixed Voltage	720.0	95.0

The following are the assumptions and considerations taken for the simulation model:

- The output DC voltage of 120 kW and 60 kW DC fast and slow chargers respectively have been considered at 720 V
- The efficiencies of 120 kW charger and 60 kW charger have been assumed to be 95%
- The power factor for the selected feeder has been assumed to be 95%
- The harmonic injections spectrum for EVSE has been assumed to be same as that of the harmonic measured at EVSE – Lake depot, Kolkata

The system studies have been conducted for the following scenarios:

Table 3-6: Different scenarios considered for load flow study

Sl No	Case	Description	Harmonic Assessment Considered	Load Growth Year	Load Growth (%)	EV Load (kW)
1	Case 1	As-Is (without EVSE)	No	2022	0	0
2	Case 2	As- Is (with EVSE)	Yes	2022	0	300
3	Case 3	2-Yr Load Growth	Yes	2024	5	780

4	Case 4	5-Yr Load Growth	Yes	2027	5	1740

- **Case 1**: For As-Is scenario, network is considered without EVSE chargers to perform load flow analysis
- **Case 2**: For As-Is scenario, network is considered with all the 7 EVSEs connected to perform load flow and harmonic analysis
- **Case 3**: For 2024 scenario, 5% of load growth per year with new EVSEs are considered on As-Is network to perform load flow and harmonic analysis
- **Case 4**: For 2027 scenario, 5% of load growth per year with new EVSEs are considered to perform load flow and harmonic analysis on As-Is network

The table below indicates the distribution network scenario gradually in five years starting from the year 2022 with a load growth of 5% annually over the conventional network and the impact of the EVSE load on the network.

Table 3-7: Summary of load flow study of different scenario

Objective	Case 1: 2022 (W/O EVSE)	Case 2: 2022 (With EVSE)	Case 3: 2024 (With EVSE)	Case 4: 2027 (With EVSE)
Peak Load (kW) in Deodar	1546.86	1886.348	2587.81	3966.18
Total Source Dispatch (kW)	1501.08	1501.09	1654.96	1915.80
Total Source Dispatch (kVA)	1583.36	1956.040	2726.89	4281.59
Total Load (kW) (including EV-AC Load & 5 % Increment/year)	0	2188.60	2434.94	3655.80
Total Loss (kW)	45.78	84.98	152.24	309.07
Total EV Load (kW)	0	300.00	780	1740
Total Source (kVAR)	338.04	517.47	881.55	1612.90
Total Loss (kVAR)	50.7	232.18	544.87	1201.58
No. of Overloaded Elements	0	4	11	26
No. of Under-Voltage Sections	0	12	37	86

Apart from the impact depicted above indicating increased power losses compared to without the EVSE scenario as well as incremental overloading situations. It was further observed that the fault current of some lines and cables was exceeding the rated withstand capacity after performing harmonic load flow analysis.

3.5.2 Power Flow and Harmonic Analysis

Power flow analysis is carried out for different cases on the existing network and identifying the abnormal conditions if any, such as over loading of the distribution network etc. The objective of a load flow is to analyse the steady state performance of the power system under various operating conditions.

Harmonic analysis is carried out for different cases on the existing network and EVSE evaluating the impact of EVSE on the electrical network with respect to IEEE 519 standard. Integration of EVSE may have adverse effect on the distribution network if the penetration is not carefully and systematically planned due to the nonlinear nature of EVSE load that generate harmonics, which can cause abnormal operation such as increased losses, reduced efficiency, temperature rise, premature insulation and winding failures.

3.5.3 Load Flow of As-Is 2022 Scenario of Lake Depot

In the As-Is scenario of 2022, initially the load flow analysis is conducted without EVSE load, as the feeder is supplying power to other locations also. The tables below depict the power flow situation without the EVSE load. The total losses in the system estimated as 45.78 kW.

Table 3-8: Load flow summary of Deodar Feeder without EVSE in 2022 scenario

Study Parameters				
Calculation Method	**Voltage Drop - Unbalanced**			
Tolerance	0.01 %			
Load Factors	Global (P=100.00%, Q=100.00%)			
Shunt Capacitors	On			
Sensitivity Load Model	From Library			
Total Summary	**kW**	**kVAR**	**kVA**	**PF (%)**
Sources (Swing)	1546.86	338.04	1583.37	97.69
Generators	0.00	0.00	0.00	0.00
Total Generation	**1546.86**	**338.04**	**1583.37**	**97.69**
Load read (Non-adjusted)	1501.08	488.68	1578.63	95.09
Load used (Adjusted)	1501.09	488.71	1578.64	95.09
EV DC load	**0.00**	**0.00**	**0.00**	**0.00**
Shunt capacitors (Adjusted)	0.00	0.00	0.00	0.00
Shunt reactors (Adjusted)	0.00	0.00	0.00	0.00
Motors	0.00	0.00	0.00	0.00
Total Loads	**1501.09**	**488.71**	**1578.64**	**95.09**
Cable Capacitance	0.00	-201.36	201.36	0.00
Line Capacitance	0.00	-0.03	0.03	0.00
Total Shunt Capacitance	**0.00**	**-201.40**	**201.40**	**0.00**
Line Losses	0.10	0.23	0.24	39.43
Cable Losses	30.08	8.34	31.22	96.37
Transformer Load Losses	8.44	42.20	43.04	19.61
Transformer No-Load Losses	7.16	0.00	7.16	100.00
Total Losses	**45.78**	**50.76**	**68.36**	**66.97**

Annual System Losses	**kW**	**MW-h/year**
Line Losses	0.10	0.85
Cable Losses	30.08	263.52
Transformer Load Losses	8.44	73.94
Transformer No-Load Losses	7.16	62.71
Total Losses	45.78	401.01

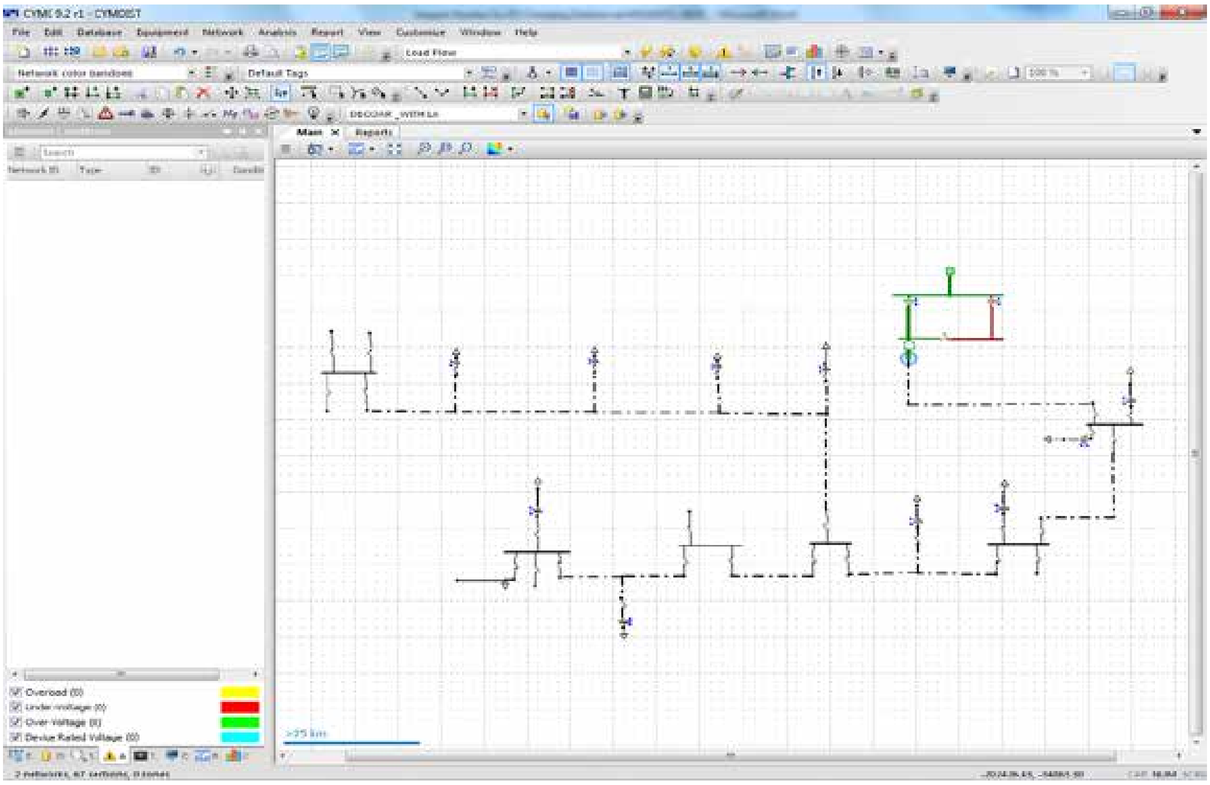


Figure 3-37: Deodar feeder without EVSE in 2022 scenario

Table 3-9: Feeder loading report of Prince Anwar Shah substation

Feeder Loading Report															
	Total Load	**Total Load**		**Cond Losses**		**Xfo Losses**		**Variable Losses**		**Fixed Losses**		**Total Losses**			
Network ID	**kVA**	**kW**	**PF (%)**	**kW**	**kVAR**	**kW**	**kVAR**	**kW**	**kVAR**	**kW**	**kVAR**	**kW**	**kVAR**	**kVA**
PRINCE ANWER SHAH-SS	1583.37	1546.86	97.69	0.06	0.15	1.67	3.84	0.83	3.99	0.90	0.00	1.73	3.99	4.35
DEODAR_FDR	1580.83	1545.13	97.74	30.11	8.41	13.93	38.36	37.78	46.77	6.26	0.00	44.04	46.77	64.25
Summary														
	Total Load	**Total Load**		**Cond Losses**		**Xfo Losses**		**Variable Losses**		**Fixed Losses**		**Total Losses**		
	kVA	**kW**	**PF (%)**	**kW**	**kVAR**	**kW**	**kVAR**	**kW**	**kVAR**	**kW**	**kVAR**	**kW**	**kVAR**	**kVA**
Total	1583.37	1546.86	97.69	30.18	8.56	15.60	42.20	38.62	50.76	7.16	0.00	45.77	50.76	68.35

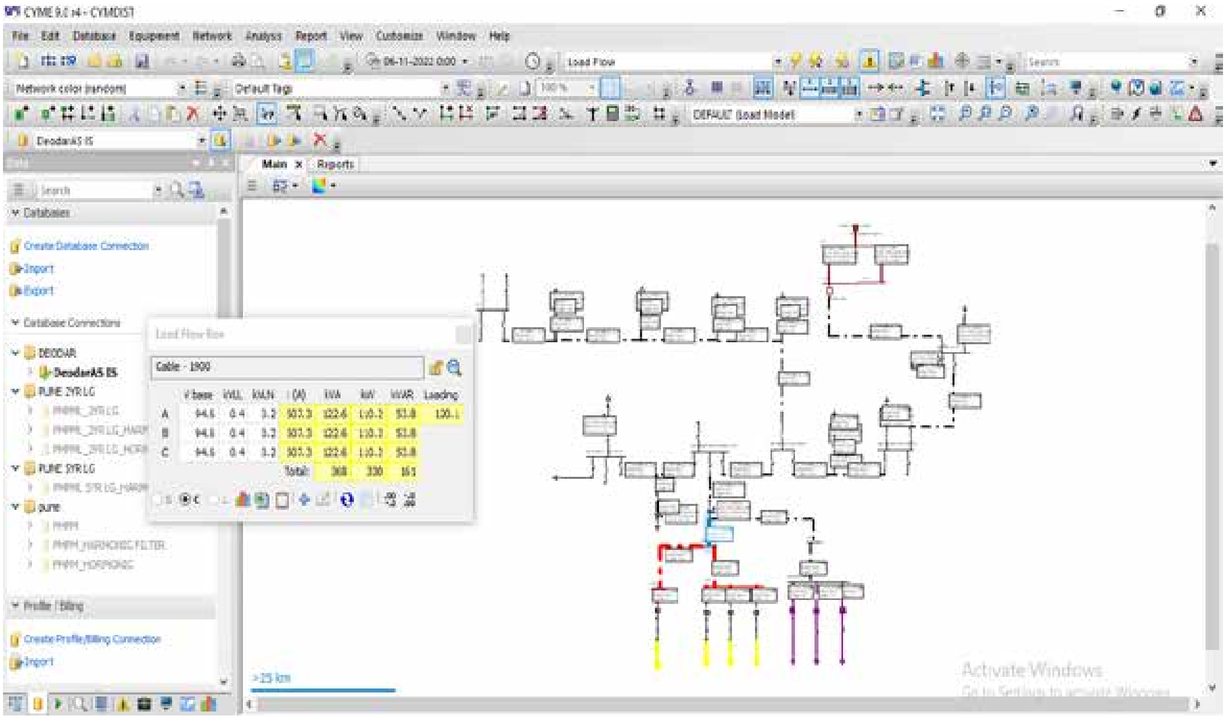
In the As-Is scenario of 2022, load flow analysis is conducted **with EVSE load** of four EVSEs – 3 x 60 kW and 1 x 120 kW (double gun), to match the sanctioned load of Lake depot of 315 kW. The tables below depict the power flow situation with the EVSE load, and its impact on the grid. The total losses in the system estimated as 84.98 kW.

Table 3-10: Load flow summary of Deodar Feeder with EVSE 2022 scenario

Study Parameter				
Calculation Method	**Voltage Drop - Unbalanced**			
Tolerance	0.01 %			
Load Factors	Global (P=100.00%, Q=100.00%)			
Sensitivity Load Model	From Library			
Total Summary	**kW**	**kVAR**	**kVA**	**PF (%)**
Sources (Swing)	1886.35	517.48	1956.04	96.44
Generators	0.00	0.00	0.00	0.00
Total Generation	**1886.35**	**517.48**	**1956.04**	**96.44**
Load read (Non-adjusted)	1501.08	488.68	1578.63	95.09
Load used (Adjusted)	1501.10	488.72	1578.65	95.09
EV DC Load	**300.00**	**154.00**	**351.00**	
Shunt capacitors (Adjusted)	0.00	0.00	0.00	0.00
Shunt reactors (Adjusted)	0.00	0.00	0.00	0.00
Motors	0.00	0.00	0.00	0.00
Total Loads	**1801.10**	**642.72**	**1929.65**	**95.09**
Cable Capacitance	0.13	-203.34	203.34	-0.06
Line Capacitance	0.00	-0.03	0.03	0.00
Total Shunt Capacitance	**0.13**	**-203.37**	**203.37**	**-0.06**
Line Losses	0.13	0.30	0.33	39.43
Cable Losses	49.28	20.27	53.28	92.48
Transformer Load Losses	11.72	58.58	59.74	19.61
Transformer No-Load Losses	8.05	0.00	8.05	100.00
Total Losses	**84.98**	**232.18**	**247.24**	**34.37**

Annual System Losses	**kW**	**MW-h/year**
Line Losses	0.13	5.93
Cable Losses	49.28	451.83
Transformer Load Losses	11.72	131.10
Transformer No-Load Losses	8.05	70.16
Total Losses	84.98	883.95

In this scenario, the difference between the adjusted and non-adjusted loads mentioned in the above table is small and hence less abnormal condition (overloaded, under voltage) present in the network which is under tolerance limits.



Load Flow Box

Cable - 1900

	V base	kVLL	kVLN	I (A)	kVA	kW	kVAR	Loading
A	94.6	0.4	3.2	507.3	122.6	110.2	53.8	120.1
B	94.6	0.4	3.2	507.3	122.6	110.2	53.8	
C	94.6	0.4	3.2	507.3	122.6	110.2	53.8	
				Total:	368	330	161	

Figure 3-38: Undervoltage and overload scenarios at Deodar feeder with EVSE in 2022

The voltage profile for 6 kV Deodar Feeder from Prince Anwar Shah 33/6 kV MUSS has been plotted in the figure below. There is a problem of low voltage in per unit persisting in the feeder which drops the base voltage to as low as 92.0 V per unit (compared to 100 V per unit) at a distance of 2095m from the feeder head approximately in 2022 scenario.

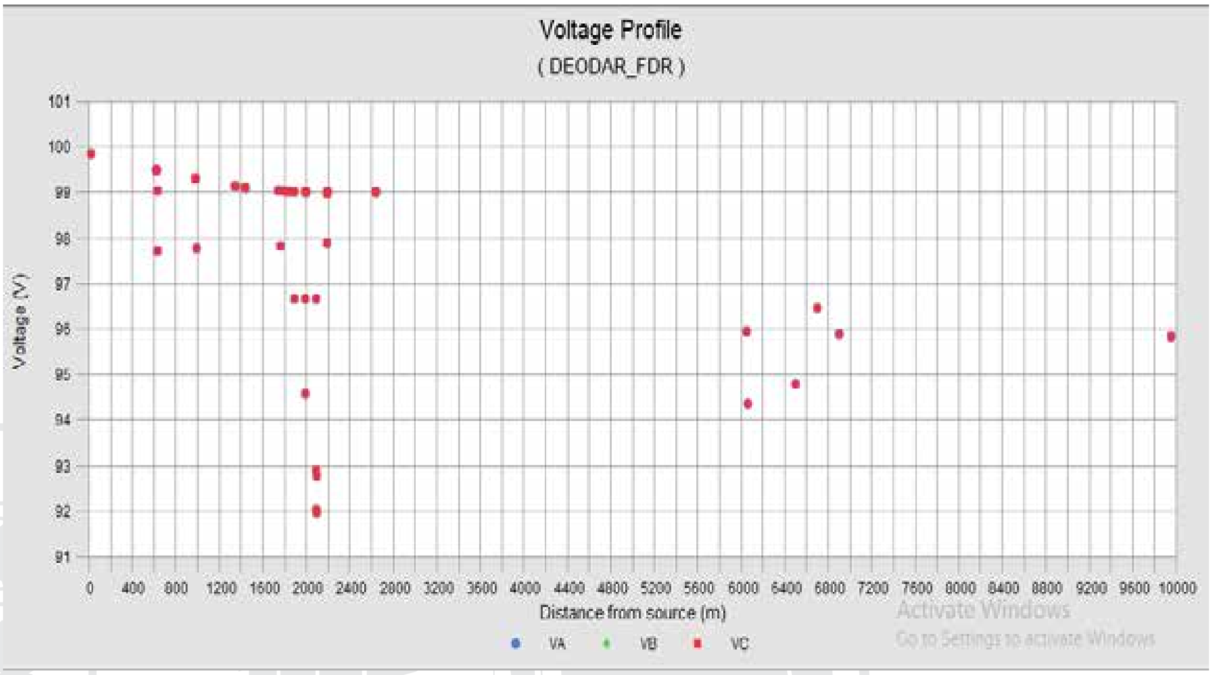


Figure 3-39: Voltage profile at Deodar feeder with EVSE in 2022 scenario

Table 3-11: Feeder loading report of Prince Anwar shah substation

Feeder Loading Report															
	Total Load	Total Load		Current (A)	Cond Losses		Xfo Losses		Variable Losses		Fixed Losses		Total Losses		
Network ID	kVA	kW	PF (%)	A	kW	kVAR	kW	kVAR	kW	kVAR	kW	kVAR	kW	kVAR	kVA
PRINCE ANWER SHAH - SS	1956.04	1886.35	96.44	34.22	0.10	0.23	2.07	5.86	1.27	6.08	0.90	0.00	2.17	6.08	6.46
DEODAR_FDR	1952.35	1884.17	96.51	188.12	49.30	20.34	17.70	52.72	75.80	226.09	7.15	0.00	82.96	226.09	240.83
Summary															
	Total Load	Total Load		Current (A)	Cond Losses		Xfo Losses		Variable Losses		Fixed Losses		Total Losses		
	kVA	kW	PF (%)	A	kW	kVAR	kW	kVAR	kW	kVAR	kW	kVAR	kW	kVAR	kVA
Total	1956.04	1886.35	96.44	222.34	49.40	20.57	19.77	58.58	77.07	232.17	8.05	0.00	85.13	232.17	247.29

3.5.4 Load Flow of 2024 Scenario of Kolkata Bus Depot

In the 2024 scenario, initially the load flow analysis is conducted **without EVSE load**, as the feeder is supplying power to other location also. The tables below depict the load flow situation without the EVSE load. The total losses in the system estimated as 54.56 kW.

Table 3-12: Load flow summary of Deodar Feeder without EVSE load in 2024 scenario

Study Parameters				
Calculation Method	**Voltage Drop - Unbalanced**			
Tolerance	0.01 %			
Load Factors	Global (P=100.00%, Q=100.00%)			
Shunt Capacitors	On			
Sensitivity Load Model	From Library			
Total Summary	**kW**	**kVAR**	**kVA**	**PF (%)**
Sources (Swing)	1709.50	399.94	1755.66	97.37
Generators	0.00	0.00	0.00	0.00
Total Generation	**1709.50**	**399.94**	**1755.66**	**97.37**
Load read (Non-adjusted)	1654.94	538.77	1740.44	95.09
Load used (Adjusted)	1654.95	538.81	1740.46	95.09
EV DC Load	**0.00**	**0.00**	**0.00**	**0.00**
Shunt capacitors (Adjusted)	0.00	0.00	0.00	0.00
Shunt reactors (Adjusted)	0.00	0.00	0.00	0.00
Motors	0.00	0.00	0.00	0.00
Total Loads	**1654.95**	**538.81**	**1740.46**	**95.09**
Cable Capacitance	0.00	-201.03	201.03	0.00
Line Capacitance	0.00	-0.03	0.03	0.00
Total Shunt Capacitance	**0.00**	**-201.07**	**201.07**	**0.00**
Line Losses	0.12	0.28	0.30	39.43
Cable Losses	36.96	10.25	38.36	96.37
Transformer Load Losses	10.34	51.71	52.74	19.61
Transformer No-Load Losses	7.13	0.00	7.13	100.00
Total Losses	**54.56**	**62.24**	**82.76**	**65.92**

Annual System Losses	**kW**	**MW-h/year**
Line Losses	0.12	1.04
Cable Losses	36.96	323.80
Transformer Load Losses	10.34	90.60
Transformer No-Load Losses	7.13	62.47
Total Losses	54.56	477.91

In this 2024 scenario, load flow analysis is conducted with EVSE load of 780 kW is considered. Two number of 500 kVA transformer are required in the scenario. The model estimates the total losses at 152.24 kW. The number of overloaded and abnormal elements have also increased.

Table 3-13: Load flow summary of Deodar Feeder with EVSE load in 2024 scenario

Study Parameters				
Calculation Method	**Voltage Drop - Unbalanced**			
Tolerance	0.01 %			
Load Factors	Global (P=100.00%, Q=100.00%)			
Sensitivity Load Model	From Library			
Total Summary	**kW**	**kVAR**	**kVA**	**PF(%)**
Sources (Swing)	2587.81	881.56	2733.85	94.66
Generators	0.00	0.00	0.00	0.00
Total Generation	**2587.81**	**881.56**	**2733.85**	**94.66**
Load read (Non-adjusted)	1654.94	538.77	1740.44	95.09
Load used (Adjusted)	1654.97	538.83	1740.48	95.09
EV DC Load	**780.00**	**400.00**	**913.00**	
Shunt capacitors (Adjusted)	0.00	0.00	0.00	0.00
Shunt reactors (Adjusted)	0.00	0.00	0.00	0.00
Motors	0.00	0.00	0.00	0.00
Total Loads	**2434.97**	**938.83**	**2653.48**	**95.09**
Cable Capacitance	0.21	-202.02	202.02	-0.10
Line Capacitance	0.00	-0.03	0.03	0.00
Total Shunt Capacitance	**0.21**	**-202.05**	**202.05**	**-0.10**
Line Losses	0.23	0.54	0.59	39.43
Cable Losses	80.57	39.16	89.58	89.94
Transformer Load Losses	21.45	107.27	109.39	19.61
Transformer No-Load Losses	8.89	0.00	8.89	100.00
Total Losses	**152.24**	**544.87**	**565.74**	**26.91**

Annual System Losses	kW	MW-h/year
Line Losses	0.23	2.02
Cable Losses	80.57	705.80
Transformer Load Losses	21.45	187.93
Transformer No-Load Losses	8.89	77.87
Total Losses	152.24	1333.59

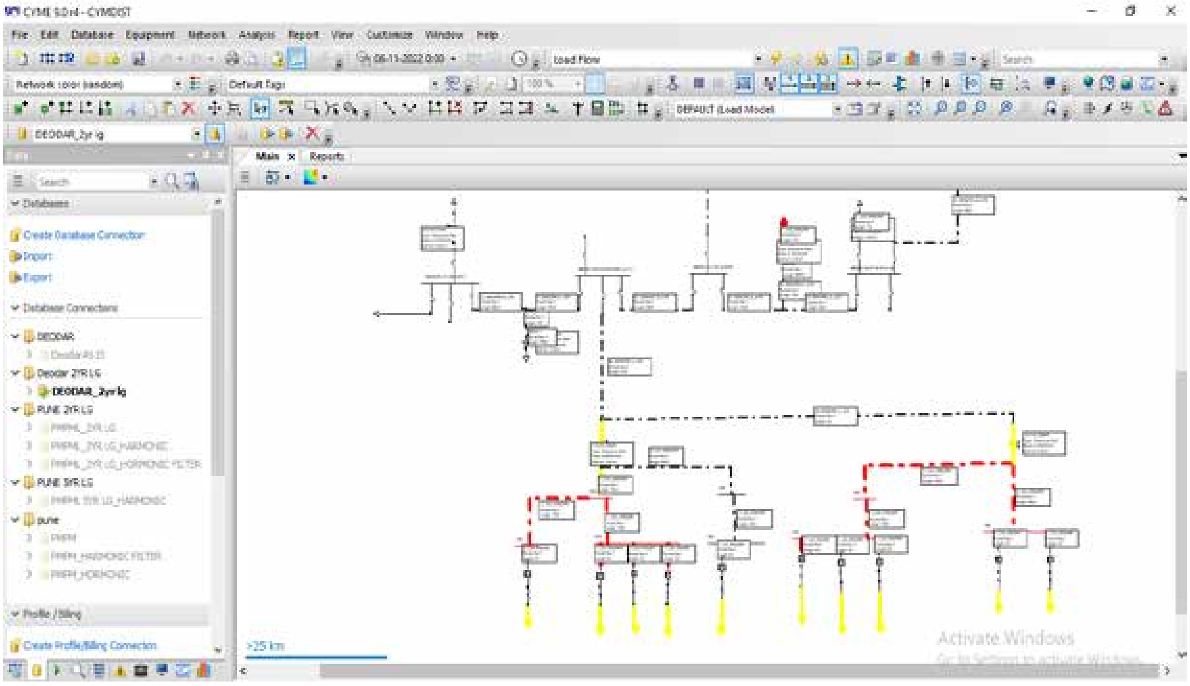


Figure 3-40: Undervoltage and overload scenarios at Deodar feeder with EVSE in 2024

The voltage profile for 6 kV Deodar feeder of Prince Anwar Shah 33/6 kV MUSS has been plotted in the below figure. In this scenario, the difference between the adjusted and non-adjusted loads mentioned in the above table is small and hence less abnormal condition (overloaded, under voltage) present in the network which is under tolerance limits.

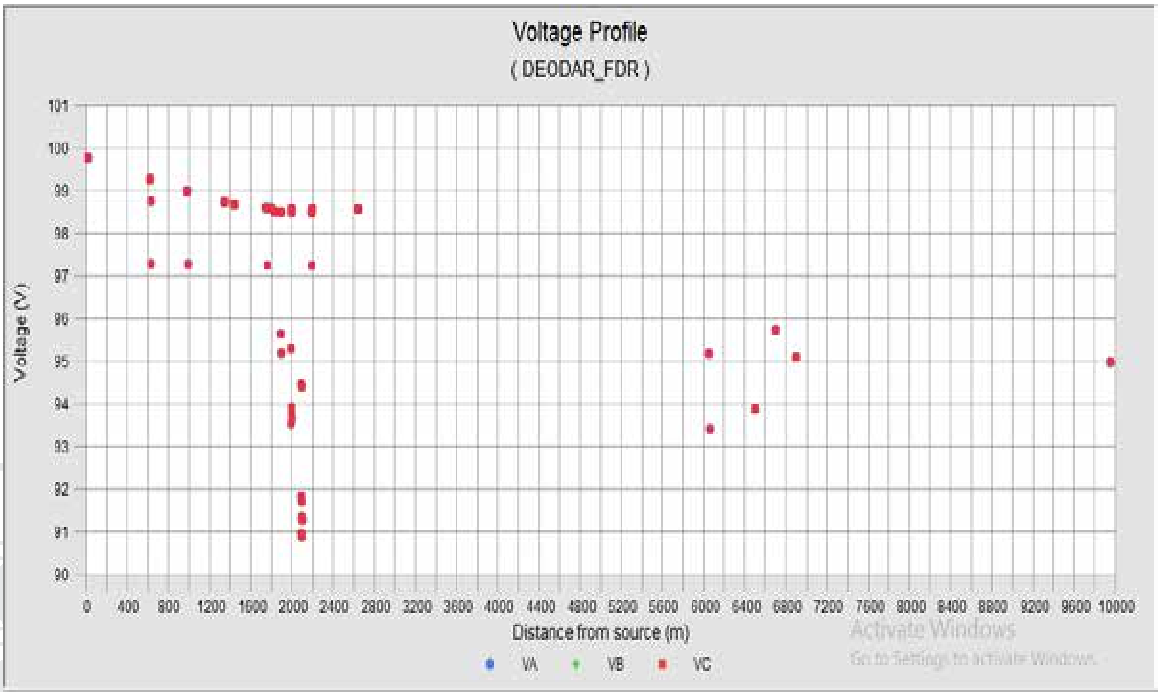


Figure 3-41: Voltage profile at Deodar feeder with EVSE in 2024 scenario

3.5.5 Load Flow of 2027 Scenario of Kolkata Bus Depot

In the 2027 scenario, initially the load flow analysis is conducted **without EVSE load**, as the feeder is supplying power to other location also. The Tables below depict the load flow situation without the EVSE load. The total losses in the system estimated as 71.76 kW.

Table 3-14: Load flow summary of Kolkata bus depot (feeder) without EVSE 2027 scenario

Study Parameters				
Calculation Method	**Voltage Drop - Unbalanced**			
Tolerance	0.01 %			
Load Factors	Global (P=100.00%, Q=100.00%)			
Shunt Capacitors	On			
Sensitivity Load Model	From Library			
Total Summary	**kW**	**kVAR**	**kVA**	**PF(%)**
Sources (Swing)	1987.57	507.85	2051.42	96.89
Generators	0.00	0.00	0.00	0.00
Total Generation	**1987.57**	**507.85**	**2051.42**	**96.89**
Load read (Non-adjusted)	1915.81	623.70	2014.77	95.09
Load used (Adjusted)	1915.80	623.70	2014.77	95.09
EV DC Load	**0.00**	**0.00**	**0.00**	
Shunt capacitors (Adjusted)	0.00	0.00	0.00	0.00
Shunt reactors (Adjusted)	0.00	0.00	0.00	0.00
Motors	0.00	0.00	0.00	0.00
Total Loads	**1915.80**	**623.70**	**2014.77**	**95.09**
Cable Capacitance	0.00	-200.46	200.46	0.00
Line Capacitance	0.00	-0.03	0.03	0.00
Total Shunt Capacitance	**0.00**	**-200.49**	**200.49**	**0.00**
Line Losses	0.16	0.37	0.41	39.43
Cable Losses	50.46	13.99	52.36	96.37
Transformer Load Losses	14.05	70.27	71.67	19.61
Transformer No-Load Losses	7.09	0.00	7.09	100.00
Total Losses	**71.76**	**84.64**	**110.97**	**64.67**

Annual System Losses	**kW**	**MW-h/year**
Line Losses	0.16	1.41
Cable Losses	50.46	442.03
Transformer Load Losses	14.05	123.12
Transformer No-Load Losses	7.09	62.07
Total Losses	71.76	628.63

In this 2027 scenario, load flow analysis is conducted **with EVSE load of 1740 kW.** Four number of 500 kVA transformers are required in the scenario. The model estimates the total losses at 309.07 kW. The number of overloaded and abnormal elements have also increased.

Table 3-15: Load flow summary of Kolkata bus depot (feeder) with EVSE 2027 scenario

Study Parameters				
Calculation Method	**Voltage Drop - Unbalanced**			
Tolerance	0.01 %			
Load Factors	Global (P=100.00%, Q=100.00%)			
Sensitivity Load Model	From Library			
Total Summary	**kW**	**kVAR**	**kVA**	**PF (%)**
Sources (Swing)	3966.18	1612.91	4281.60	92.63
Generators	0.00	0.00	0.00	0.00
Total Generation	**3966.18**	**1612.91**	**4281.60**	**92.63**
Load read (Non-adjusted)	1915.81	623.70	2014.77	95.09
Load used (Adjusted)	1915.81	623.68	2014.77	95.09
EV DC Load	**1740.00**	**891.00**	**2038.00**	
Shunt capacitors (Adjusted)	0.00	0.00	0.00	0.00
Shunt reactors (Adjusted)	0.00	0.00	0.00	0.00
Motors	0.00	0.00	0.00	0.00
Total Loads	**3655.81**	**1514.68**	**4052.77**	**95.09**
Cable Capacitance	0.36	-212.13	212.13	-0.17
Line Capacitance	0.00	-0.03	0.03	0.00
Total Shunt Capacitance	**0.36**	**-212.17**	**212.17**	**-0.17**
Line Losses	0.52	1.22	1.33	39.43
Cable Losses	162.47	93.23	187.32	86.73
Transformer Load Losses	43.91	219.57	223.92	19.61
Transformer No-Load Losses	10.51	0.00	10.51	100.00
Total Losses	**309.07**	**1201.59**	**1240.70**	**24.91**

Annual System Losses	**kW**	**MW-h/year**
Line Losses	0.52	4.58
Cable Losses	162.47	1423.22
Transformer Load Losses	43.91	384.69
Transformer No-Load Losses	10.51	92.04
Total Losses	309.07	2707.45

In this scenario, the difference between the adjusted and non-adjusted loads mentioned in the above table is small and hence less abnormal condition (overloaded, under voltage) present in the network which is under tolerance limits.

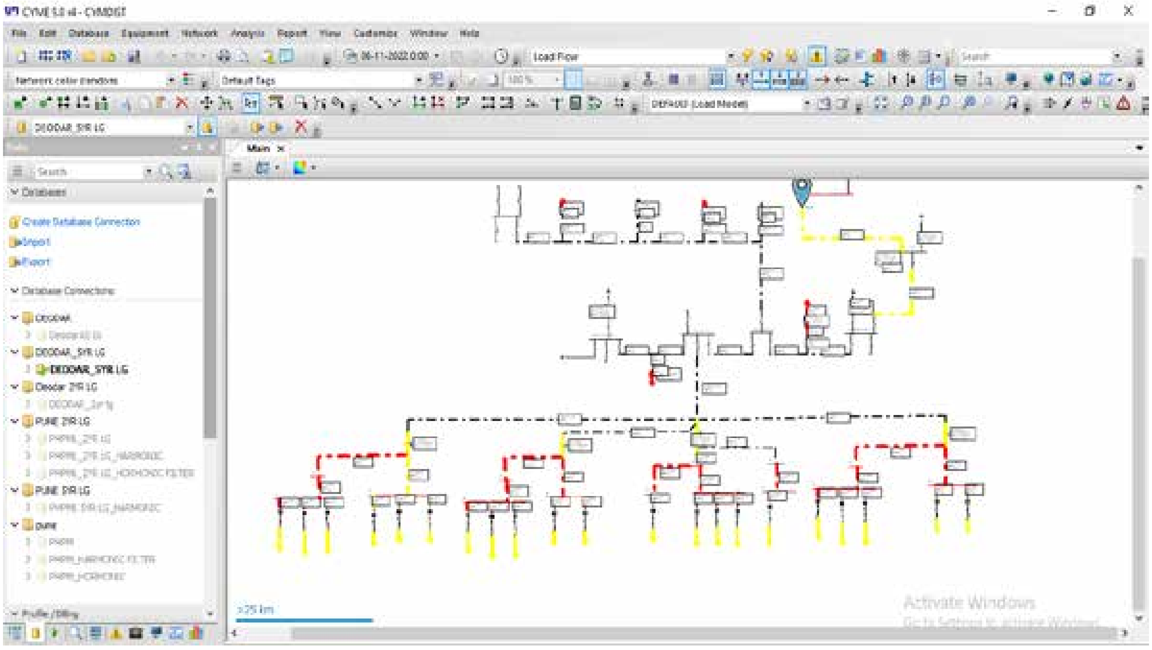


Figure 3-42: Undervoltage and overload scenarios at Deodar feeder with EVSE in 2027

The voltage profile for 6 kV Deodar Feeder of Prince Anwar Shah 33/6 kV MUSS has been plotted in the below in Figure. There is a problem of low in per unit voltage persisting in the feeder which drops the base voltage toas low as 89.1 V per unit (compared to 100 V per unit) at a distance of 2240m from the feeder head approximately in the year 2027 scenario.

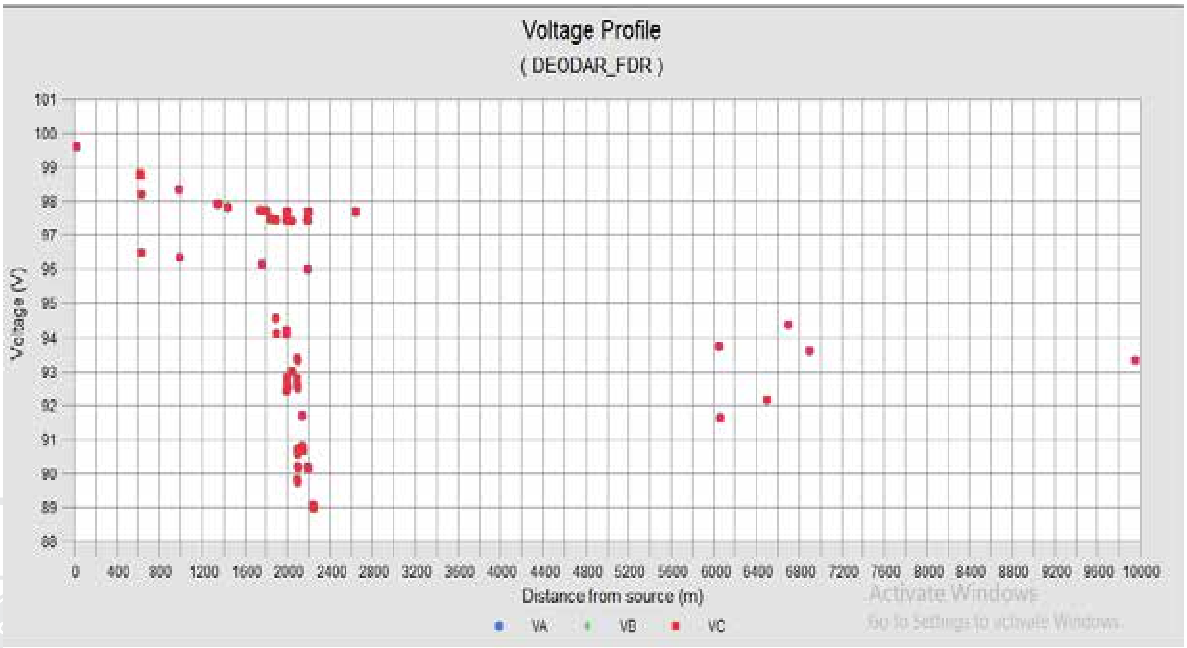


Figure 3-43: Voltage profile at Deodar feeder with EVSE in 2027 scenario

3.5.6 Harmonics Impact Study

The Lake depot charging station is fed from 6 kV Deodar feeder and the EVSE considered for the analysis are given below:

Sl No	Particulars	No. of Units	Load of each unit	Total Load (kW)
1	DC Charging Unit (fast charging)	1	120	120
2	DC Charging Unit (slow charger)	3	60	180

Here, only 1x 120 kW and 3x60 kW DC chargers are considered to match the sanctioned load of 315 kW of Lake depot, Kolkata. The individual and total voltage and current harmonics details were captured at one of EV installation sites in Kolkata.

Table 3-16: Voltage Harmonics (%) injected by EVSE recorded by PQM

Harmonic Order	Voltage Harmonics (%)		
	V_{RN}	V_{YN}	V_{BN}
3rd	0.385331	0.538628	0.605662
5th	1.687119	1.753781	1.246223
7th	2.112073	2.224844	1.805233
9th	0.359106	0.155708	0.409191
11th	0.543628	0.715504	0.601057
13th	0.123146	0.218028	0.257327
15th	0.068271	0.039134	0.090157
17th	0.151657	0.197376	0.174186
19th	0.078255	0.111153	0.113501

3.5.7 Harmonic Analysis for As-Is 2022 scenario

Below is the **harmonic voltage analysis** report after analysing the impact at the PSS and its nearby network at the Deodar feeder. The study indicates that the Total Harmonic Distortion (THD) lies between 3-4%.

Table 3-17: Voltage harmonic distortion analysis impact in 2022 scenario

Node ID	kV L-N	150.00 Hz IHD (%)	250.00 Hz IHD (%)	350.00 Hz IHD (%)	450.00 Hz IHD (%)	550.00 Hz IHD (%)	650.00 Hz IHD (%)	750.00 Hz IHD (%)	850.00 Hz IHD (%)	950.00 Hz IHD (%)	THD (%)	KVT (kV)	TIF
CHARGING PANEL-120KW-1-A	0.23	0.430	1.967	2.479	0.424	0.634	0.141	0.080	0.177	0.090	3.294	3.72	16.18
CHARGING PANEL-60KW (ALL CHARGER)-2-A	0.23	0.526	2.370	2.977	0.509	0.761	0.170	0.096	0.212	0.108	3.960	4.43	19.41

Below is the **harmonic current analysis** report after analysing the impact at the PSS and its nearby network at the Deodar feeder. The study indicates that the Total Harmonic Distortion (THD) lies between 1-2%.

Table 3-18: Current harmonic distortion analysis impact in 2022 scenario

Device Number	Device Type	Fund. Current (A)	150 Hz IHD (%)	250Hz IHD (%)	350 Hz IHD (%)	450 Hz IHD (%)	550 Hz IHD (%)	650 Hz IHD (%)	750 Hz IHD (%)	850 Hz IHD (%)	950 Hz IHD (%)	THD (%)	KIT (kA)	ITIF	PCC	Isc/IL	TDD (%)
ABB RMU DEODAR RAHAMAN © O/T-A	Two-Winding Transformer	40.83	0.606	0.758	0.381	0.049	0.046	0.090	0.013	0.012	0.016	1.049	0.12	2.92	ABB RMU DEODAR RAHAM©(C) O/T-A	296.99	1.049

The results monitored at PSS charging panel presented in the below figures.

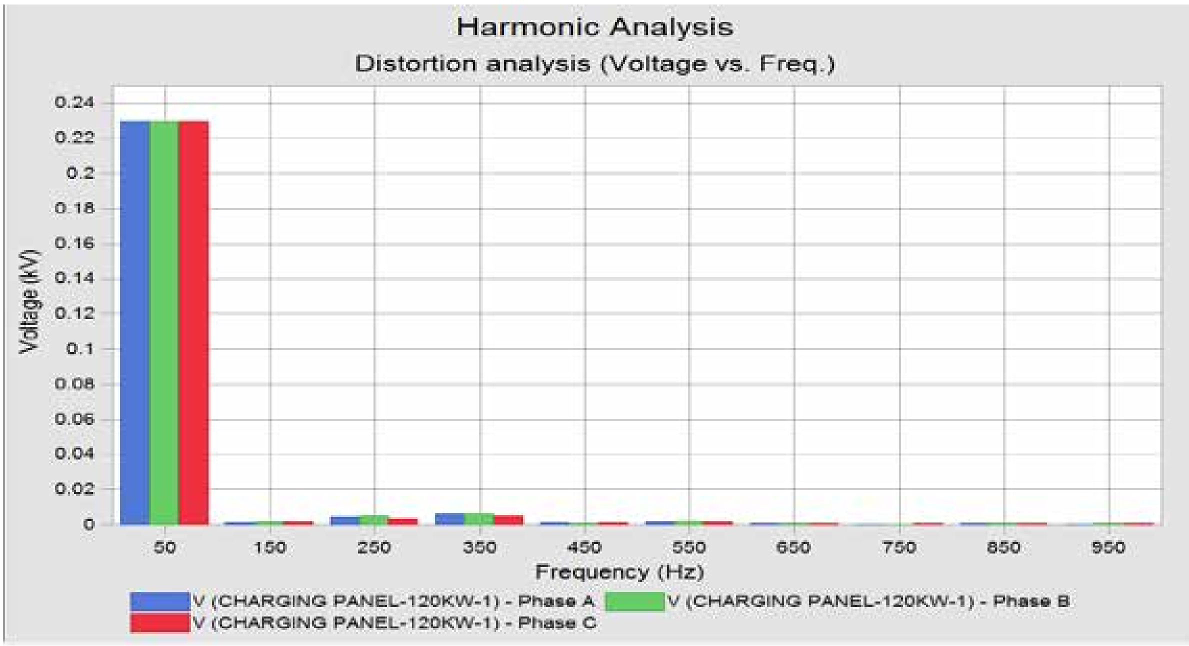


Figure 3-44: Voltage distortion at Lake depot - 120kW fast charger in 2022 scenario

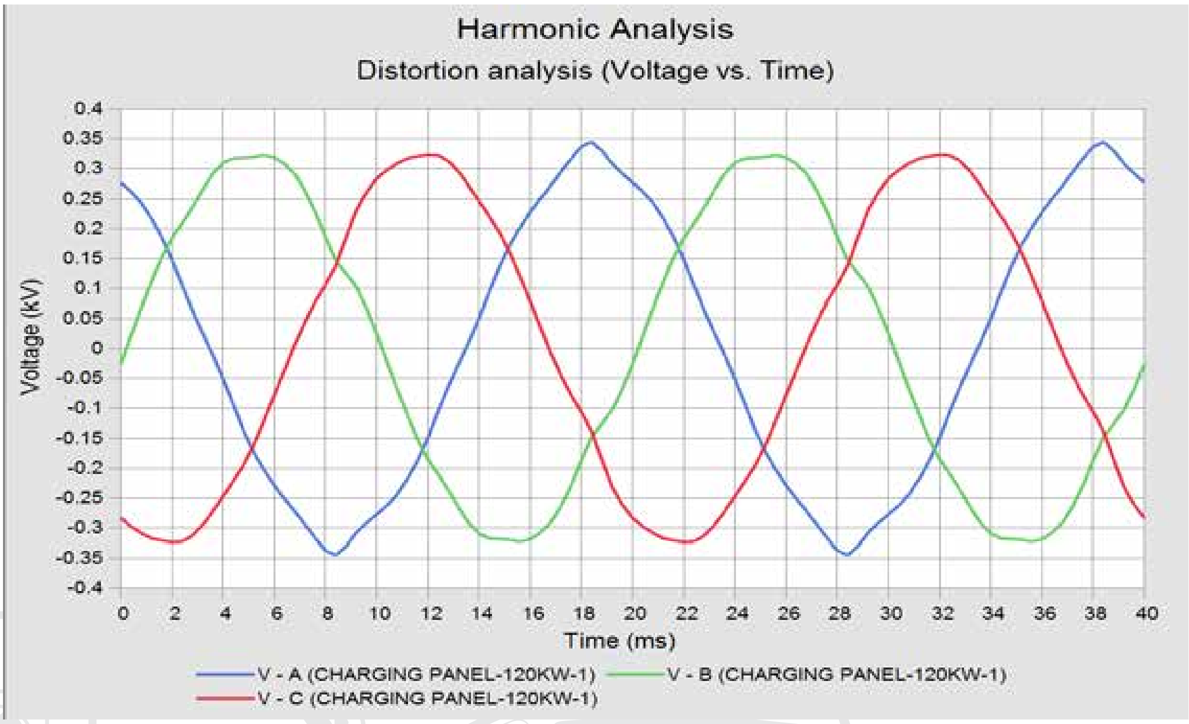


Figure 3-45: Voltage distortion at Lake depot – 120 kW fast charger in 2022 scenario

Referring to the results in above figures, it has been observed that the voltage distortions are within the limit for 5th and 7th order harmonics on the LT side of the transformer in time domain and frequency domain and are acceptable as per IEEE 519 limits.

3.5.8 Harmonic Analysis for 2024 scenario

Considering the load growth in 2024 scenario, with the total load of 780 kW, where DC fast chargers of 3x120 kW and DC slow chargers of 7x60 kW and two number of 500 kVA transformer are required in the scenario as shown in below Table.

Table 3-19: List of chargers considered at Lake depot, Kolkata in 2024 scenario

Network Id	Section Id	Type	Nominal Power (kW)	Input Voltage (kV_{LL})	Output Voltage (V)	PF (%)	Efficiency (A)	Ctrl Type	Operating Voltage (V)	Operating PF (%)
DEODAR_RAHAMAN	DEODAR-120KW FAST CHARGER	Battery Charger	150.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN	DEODAR-60KW SLOW CHARGER-1	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN	DEODAR-60KW SLOW CHARGER-2	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN	DEODAR-60KW SLOW CHARGER-3	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2024	DEODAR-60KW SLOW CHARGER-4_2024	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN-2024	DEODAR-60KW SLOW CHARGER-5_2024	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2024	DEODAR-60KW SLOW CHARGER-6_2024	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2024	DEODAR-60KW SLOW CHARGER-7_2024	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2024	DEODAR-120KW FAST CHARGER-8_2024	Battery Charger	150.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2024	DEODAR-120KW FAST CHARGER-9_2024	Battery Charger	150.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0

Table 3-20: EVSE details considered at Lake depot, Kolkata in 2024 scenario

Network Id	Section Id	Rated Voltage (V)	Rated Power (kW)	Rated current (A)
DEODAR_RAHAMAN	DEODAR-120KW FAST DC-1	720.0	120.0	166.67
DEODAR_RAHAMAN	DEODAR-60KW SLOW DC-2	720.0	60.0	83.33
DEODAR_RAHAMAN	DEODAR-60KW SLOW DC-3	720.0	60.0	83.33
DEODAR_RAHAMAN	DEODAR-60KW SLOW DC-4	720.0	60.0	83.33
DEODAR_RAHAMAN	DEODAR-60KW SLOW DC-5	720.0	60.0	83.33
DEODAR_RAHAMAN_2024	DEODAR-60KW SLOW DC-6_2024	720.0	60.0	83.33
DEODAR_RAHAMAN_2024	DEODAR-60KW SLOW DC-7_2024	720.0	60.0	83.33
DEODAR_RAHAMAN_2024	DEODAR-60KW SLOW DC-8_2024	720.0	60.0	83.33
DEODAR_RAHAMAN_2024	DEODAR-120KW FAST DC-9_2024	720.0	120.0	166.67
DEODAR_RAHAMAN_2024	DEODAR-120KW FAST DC-10_2024	720.0	120.0	166.67

In this case, the harmonics are injected in to the distribution feeder by the EVSEs. The losses and abnormal conditions in the feeder have increased due to harmonic current injection. The current amplitudes are within the limit for 5th and 7th harmonics. It was observed that, voltage further drops near to undesirable level and in that case, harmonics in the neutral conductor increases than the harmonics in the phase.

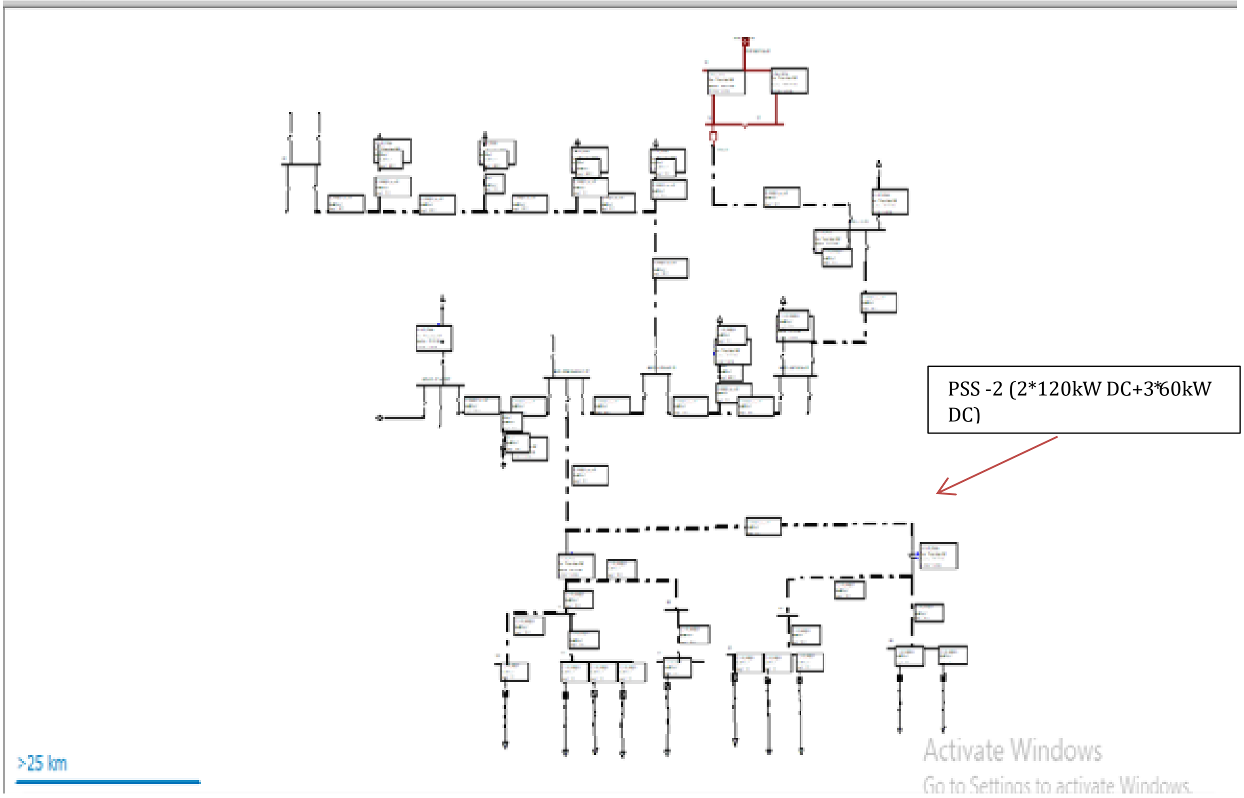


Figure 3-46: Network conditions in 2024 scenario

Below is the harmonic voltage distortion report after analysing the impact at the transformer and its nearby network at the Deodar feeder. The study indicates that the Total Harmonic Distortion (THD) lies between 2-5%.

Table 3-21: Voltage harmonic distortion analysis impact in 2024 scenario

Node ID	kV L-N	150 Hz IHD (%)	250 Hz IHD (%)	350 Hz IHD (%)	450 Hz IHD (%)	550 Hz IHD (%)	650 Hz IHD (%)	750 Hz IHD (%)	850 Hz IHD (%)	950 Hz IHD (%)	THD (%)	KVT (kV)	TIF
CHARGING PANEL-120KW-1-A	0.23	0.487	2.270	2.857	0.492	0.726	0.158	0.092	0.202	0.102	3.796	4.21	18.53
CHARGING PANEL-60KW(ALL CHARGER)-2-A	0.22	0.582	2.674	3.357	0.576	0.853	0.187	0.108	0.238	0.121	4.465	4.91	21.79
CHARGING PANEL-60KW(ALL CHARGER)-3_2024-A	0.23	0.372	1.754	2.208	0.381	0.559	0.121	0.071	0.156	0.079	2.932	3.36	14.30
CHARGING PANEL-60KW(ALL CHARGER)-4_2024-A	0.23	0.562	2.576	3.229	0.554	0.819	0.179	0.104	0.227	0.115	4.297	4.73	20.90
CHARGING PANEL-120KW-5_2024-A	0.23	0.388	1.828	2.299	0.396	0.582	0.125	0.074	0.160	0.081	3.053	3.45	14.84

Below is the harmonic current distortion report after analysing the impact at the transformer and its nearby network at the Deodar feeder. The study indicates that the Total Harmonic Distortion (THD) lies between 1-2%.

Table 3-22: Current harmonic distortion analysis impact in 2024 scenario

Device Number	Device Type	Fund. Current (A)	150.00 Hz IHD (%)	250.00 Hz IHD (%)	350.00 Hz IHD (%)	450.00 Hz IHD (%)	550.00 Hz IHD (%)	650.00 Hz IHD (%)	750.00 Hz IHD (%)	850.00 Hz IHD (%)	950.00 Hz IHD (%)	THD (%)	KIT (kA)	ITIF	PCC	Isc/IL	TDD (%)
ABB RMU DEODAR RAHAMAN (C) O/T-A	Two-Winding Transformer	49.17	0.627	0.785	0.395	0.050	0.047	0.094	0.013	0.012	0.017	1.086	0.15	3.02	ABB RMU DEODAR RAHAMAN (C) O/T-A	246.62	1.086
ABB RMU DEODAR RAHAMAN (C) O/T_2024-2-A	Two-Winding Transformer	57.63	0.560	0.697	0.350	0.045	0.042	0.083	0.012	0.011	0.015	0.966	0.15	2.68	ABB RMU DEODAR RAHAMAN (C) O/T_2024-2-A	210.04	0.966

The results are monitored at the transformer panel presented in the below figures.

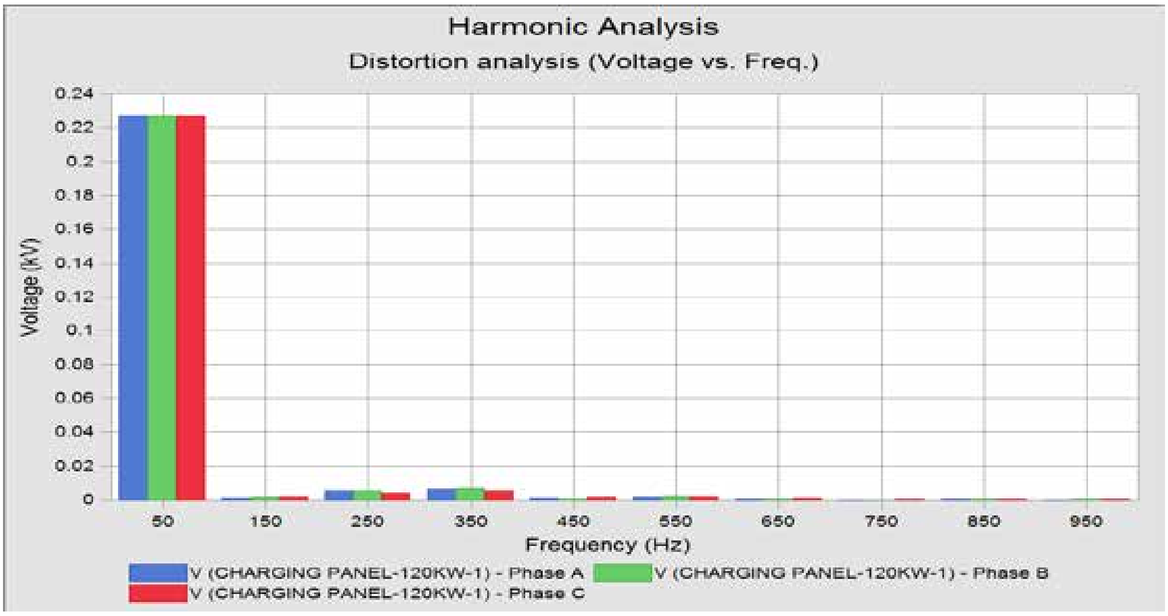


Figure 3-47: Voltage distortion at Lake depot - 120kW fast charger in 2024 scenario

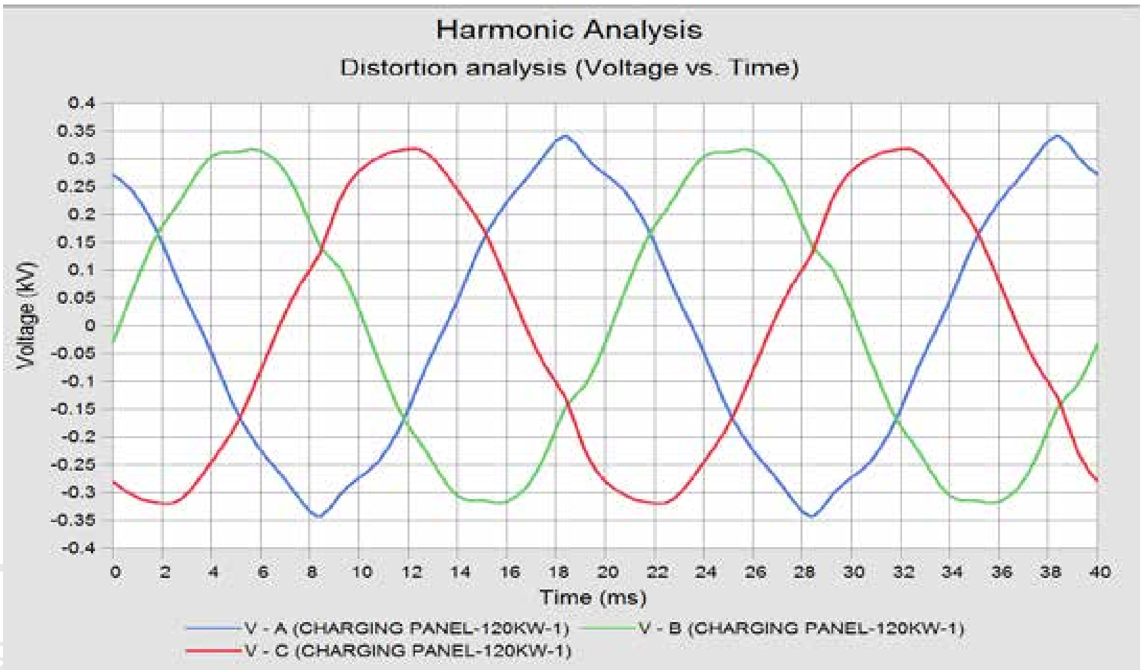


Figure 3-48: Voltage distortion at Lake depot - 120kW fast charger in 2024 scenario

Referring to the results in above figures, it has been observed that the voltage distortion are within the limit for 5th and 7th order frequencies at the cables adjacent to the EVSE, on the LT side of the transformer in time domain and frequency domain and are acceptable as per IEEE 519 limits.

3.5.9 Harmonic Analysis for 2027 scenario

Considering the load growth in 2027 scenario, with the total load of 1740 kW, where DC fast chargers of 8x120 kW and DC slow chargers of 13x60 kW and four number of 500 kVA transformer are required in the scenario as shown in below Table.

Table 3-23: List of chargers considered at Lake depot, Kolkata in 2027 scenario

Network Id	Section Id	Equipment Id	Type	Nominal Power (kW)	Input Voltage (kVLL)	Output Voltage (V)	PF (%)	Efficiency (A)	Ctrl Type	Operating Voltage (V)	Operating PF (%)
DEODAR_RAHAMAN	DEODAR-120KW FAST CHARGER	DC FAST CHARGER	Battery Charger	150.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN	DEODAR-60KW SLOW CHARGER-1	DC SLOW CHARGER	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN	DEODAR-60KW SLOW CHARGER-2	DC SLOW CHARGER	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN	DEODAR-60KW SLOW CHARGER-3	DC SLOW CHARGER	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2024	DEODAR-60KW SLOW CHARGER-4_2024	DC SLOW CHARGER	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2024	DEODAR-60KW SLOW CHARGER-5_2024	DC SLOW CHARGER	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2024	DEODAR-60KW SLOW CHARGER-6_2024	DC SLOW CHARGER	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2024	DEODAR-60KW SLOW CHARGER-7_2024	DC SLOW CHARGER	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2024	DEODAR-120KW FAST CHARGER-8_2024	DC FAST CHARGER	Battery Charger	150.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2024	DEODAR-120KW FAST CHARGER-9_2024	DC FAST CHARGER	Battery Charger	150.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	100.0
DEODAR_RAHAMAN_2027	DEODAR-60KW SLOW CHARGER-10_2027	DC SLOW CHARGER	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2027	DEODAR-60KW SLOW CHARGER-11_2027	DC SLOW CHARGER	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2027	DEODAR-60KW SLOW CHARGER-12_2027	DC SLOW CHARGER	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2027	DEODAR-60KW SLOW CHARGER-13_2027	DC SLOW CHARGER	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0

DEODAR_RAHAMAN_2027	DEODAR-60KW SLOW CHARGER-14_2027	DC SLOW CHARGER	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2027	DEODAR-60KW SLOW CHARGER-15_2027	DC SLOW CHARGER	Battery Charger	100.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2027	DEODAR-120KW FAST CHARGER-16_2027	DC FAST CHARGER	Battery Charger	150.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2027	DEODAR-120KW FAST CHARGER-17_2027	DC FAST CHARGER	Battery Charger	150.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2027	DEODAR-120KW FAST CHARGER-18_2027	DC FAST CHARGER	Battery Charger	150.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2027	DEODAR-120KW FAST CHARGER-19_2027	DC FAST CHARGER	Battery Charger	150.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0
DEODAR_RAHAMAN_2027	DEODAR-120KW FAST CHARGER-20_2027	DC FAST CHARGER	Battery Charger	150.0	0.4	720.0	90.0	95.0	Fixed Voltage	720.0	95.0

Table 3-24: EVSE details considered at Lake depot, Kolkata in 2027 scenario

Network Id	Section Id	Status	Rated Voltage (V)	Rated Power (kW)	Rated current (A)
DEODAR_RAHAMAN	DEODAR-120 kW FAST DC-1	Connected	720.0	120.0	166.67
DEODAR_RAHAMAN	DEODAR-60 kW SLOW DC-2	Connected	720.0	60.0	83.33
DEODAR_RAHAMAN	DEODAR-60 kW SLOW DC-3	Connected	720.0	60.0	83.33
'DEODAR_RAHAMAN	DEODAR-60 kW SLOW DC-4	Connected	720.0	60.0	83.33
DEODAR_RAHAMAN_2024	DEODAR-60 kW SLOW DC-5	Connected	720.0	60.0	83.33
DEODAR_RAHAMAN_2024	DEODAR-60 kW SLOW DC-6_2024	Connected	720.0	60.0	83.33
DEODAR_RAHAMAN_2024	DEODAR-60 kW SLOW DC-7_2024	Connected	720.0	60.0	83.33
DEODAR_RAHAMAN_2024	DEODAR-60 kW SLOW DC-8_2024	Connected	720.0	60.0	83.33
DEODAR_RAHAMAN_2024	DEODAR-120 kW FAST DC-9_2024	Connected	720.0	120.0	166.67
DEODAR_RAHAMAN_2024	DEODAR-120 kW FAST DC-10_2024	Connected	720.0	120.0	166.67
DEODAR_RAHAMAN_2027	DEODAR-60 kW SLOW DC-11_2027	Connected	720.0	60.0	83.33
DEODAR_RAHAMAN_2027	DEODAR-60 kW SLOW DC-12_2027	Connected	720.0	60.0	83.33
DEODAR_RAHAMAN_2027	DEODAR-60 kW SLOW DC-13_2027	Connected	720.0	60.0	83.33
DEODAR_RAHAMAN_2027	DEODAR-60 kW SLOW DC-14_2027	Connected	720.0	60.0	83.33

DEODAR_RAHAMAN_2027	DEODAR-60 kW SLOW DC-15_2027	Connected	720.0	60.0	83.33
DEODAR_RAHAMAN_2027	DEODAR-60 kW SLOW DC-16_2027	Connected	720.0	60.0	83.33
DEODAR_RAHAMAN_2027	DEODAR-120 kW FAST DC-17_2027	Connected	720.0	120.0	166.67
DEODAR_RAHAMAN_2027	DEODAR-120 kW FAST DC-18_2027	Connected	720.0	120.0	166.67
DEODAR_RAHAMAN_2027	DEODAR-120 kW FAST DC-19_2027	Connected	720.0	120.0	166.67
DEODAR_RAHAMAN_2027	DEODAR-120 kW FAST DC-20_2027	Connected	720.0	120.0	166.67
DEODAR_RAHAMAN_2027	DEODAR-120 kW FAST DC-21_2027	Connected	720.0	120.0	166.67

In this case, the harmonics are injected in to the distribution feeder by the EVSEs. The losses and abnormal conditions in the feeder have increased due to harmonic current injection. The voltage amplitudes are within the limit for 5th and 7th order harmonics. It was observed that, voltage further drops near to undesirable level and in that case, harmonics in the neutral conductor increases than the harmonics in the phase.

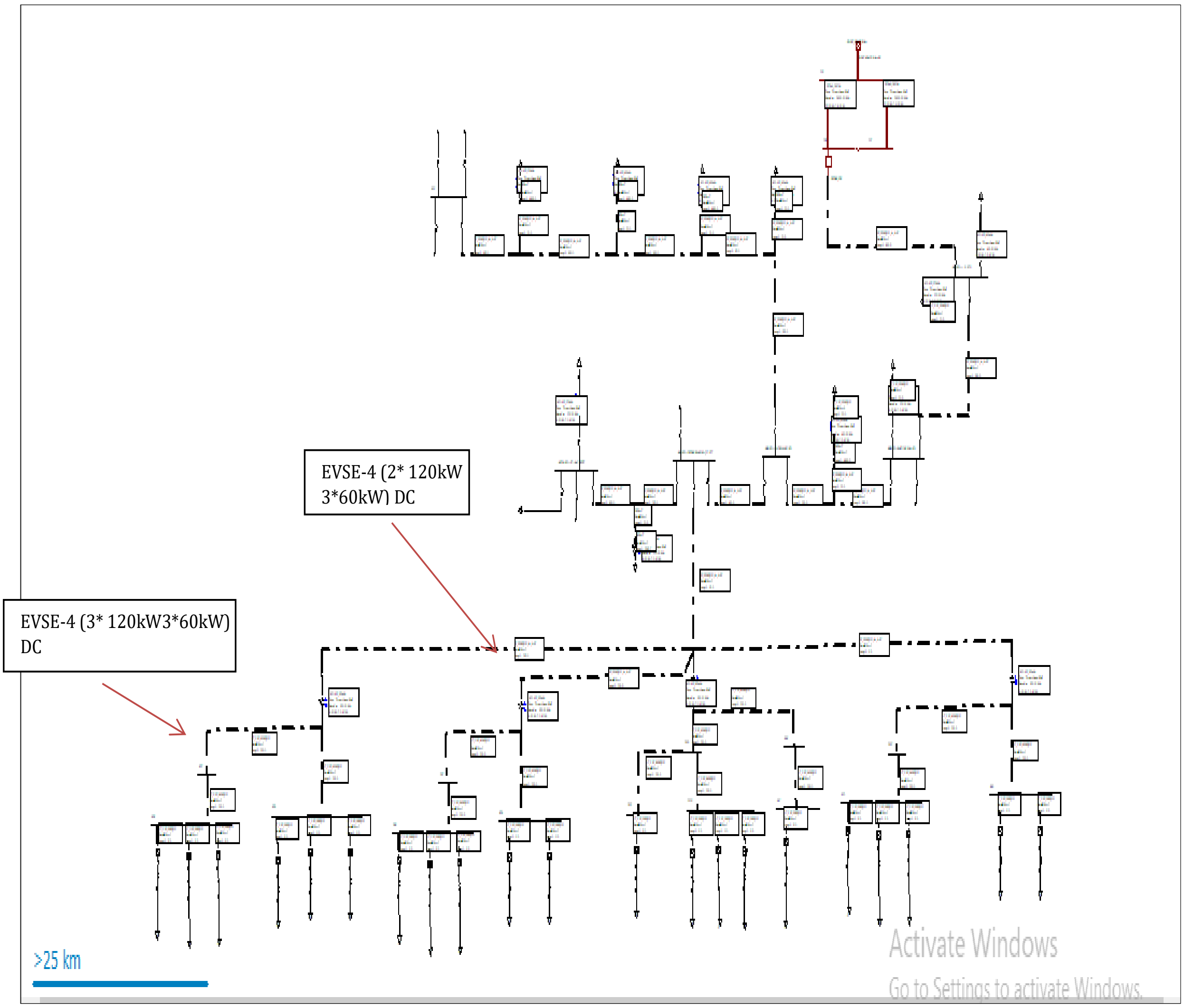


Figure 3-49: Network conditions in 2027 scenario

Below is the harmonic voltage distortion report after analysing the impact at the transformer and its nearby network at Deodar feeder. The study indicates that the Total Harmonic Distortion (THD) lies between 2-5%.

Table 3-25: Voltage harmonic distortion analysis impact in 2027 scenario

Node ID	kV L-N	150 Hz IHD (%)	250 Hz IHD (%)	350 Hz IHD (%)	450 Hz IHD (%)	550 Hz IHD (%)	650 Hz IHD (%)	750 Hz IHD (%)	850 Hz IHD (%)	950 Hz IHD (%)	THD (%)	KVT (kV)	TIF
CHARGING PANEL-120 kW-1-A	0.22	0.471	2.278	2.855	0.496	0.714	0.149	0.092	0.198	0.099	3.794	4.10	18.31
CHARGING PANEL-60 kW (ALL CHARGER)-2-A	0.22	0.566	2.681	3.356	0.581	0.842	0.177	0.108	0.234	0.117	4.464	4.79	21.57
CHARGING PANEL-60 kW (ALL CHARGER)-3_2024-A	0.23	0.357	1.762	2.207	0.385	0.549	0.112	0.071	0.153	0.076	2.932	3.27	14.11
CHARGING PANEL-60 kW (ALL CHARGER)-4_2024-A	0.22	0.546	2.584	3.228	0.559	0.807	0.169	0.104	0.223	0.111	4.296	4.61	20.67
CHARGING PANEL-120 kW-5_2024-A	0.23	0.373	1.834	2.296	0.400	0.570	0.115	0.074	0.157	0.077	3.051	3.35	14.61
CHARGING PANEL-60 kW (ALL CHARGER)-6_2027-A	0.22	0.546	2.584	3.227	0.559	0.807	0.169	0.104	0.223	0.111	4.296	4.61	20.67
CHARGING PANEL-60 kW (ALL CHARGER)-7_2027-A	0.22	0.609	2.875	3.590	0.620	0.898	0.188	0.115	0.247	0.123	4.779	5.03	22.95
CHARGING PANEL-120 kW-8_22027-A	0.22	0.476	2.304	2.882	0.500	0.719	0.148	0.093	0.197	0.098	3.833	4.10	18.38
CHARGING PANEL-120 kW-9_22027-A	0.23	0.373	1.834	2.294	0.400	0.570	0.115	0.074	0.157	0.077	3.049	3.34	14.60

Below is the harmonic current distortion report after analysing the impact at the transformer and its nearby network at the Deodar feeder. The study indicates that the Total Harmonic Distortion (THD) lies between 1-2%.

Table 3-26: Current harmonic distortion analysis impact in 2027 scenario

Device Number	Device Type	Fund. Current (A)	150 Hz IHD (%)	250 Hz IHD (%)	350 Hz IHD (%)	450 Hz IHD (%)	550 Hz IHD (%)	650 Hz IHD (%)	750 Hz IHD (%)	850 Hz IHD (%)	950 Hz IHD (%)	THD (%)	KIT (kA)	ITIF	PCC	Isc/I$_L$	TDD (%)
ABB RMU DEODAR RAHAMAN (C) O/-A	Two-Winding Transformer	50.08	0.605	0.757	0.381	0.049	0.046	0.090	0.013	0.012	0.016	1.048	0.15	2.92	ABB RMU DEODAR RAHAMAN (C) O/-A	242.16	1.048
ABB RMU DEODAR RAHAMAN (C) O/T_2024-2-A	Two-Winding Transformer	58.70	0.540	0.672	0.337	0.043	0.040	0.080	0.011	0.010	0.014	0.931	0.15	2.59	ABB RMU DEODAR RAHAMAN (C) O/T_2024-2-A	206.21	0.931
ABB RMU DEODAR RAHAMAN (C) O/T_2027-3-A	Two-Winding Transformer	58.72	0.539	0.672	0.337	0.043	0.040	0.080	0.011	0.010	0.014	0.931	0.15	2.58	ABB RMU DEODAR RAHAMAN (C) O/T_2027-3-A	199.14	0.931
ABB RMU DEODAR RAHAMAN (C) O/T_2027-4-A	Two-Winding Transformer	78.23	0.476	0.592	0.297	0.038	0.035	0.070	0.010	0.009	0.012	0.820	0.18	2.28	ABB RMU DEODAR RAHAMAN (C) O/T_2027-4-A	146.83	0.820

The results are monitored at transformer panel presented in the below figures.

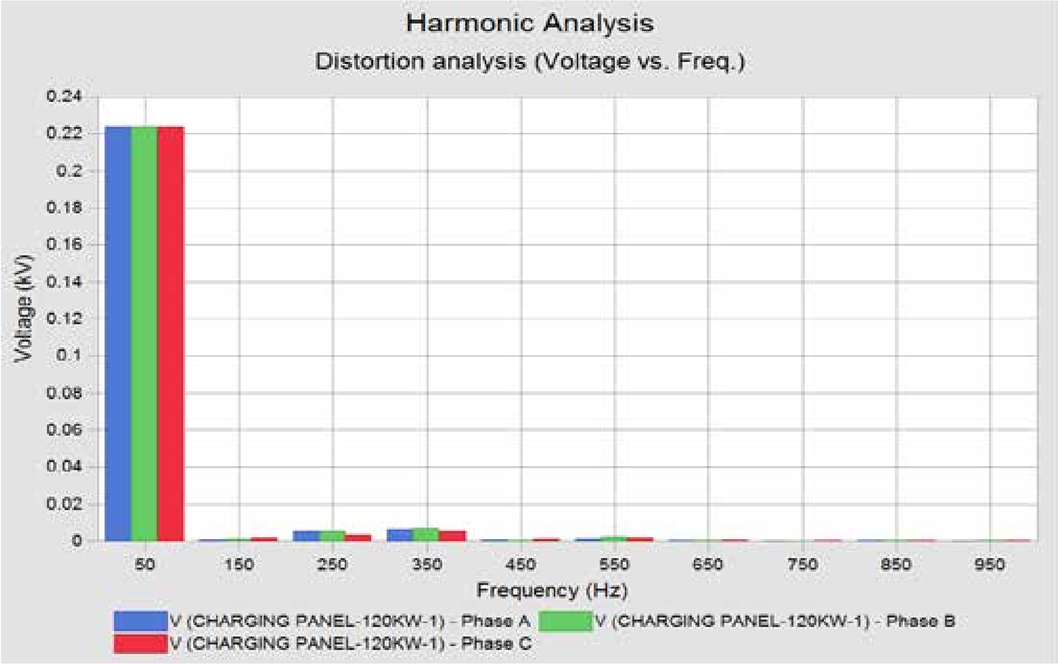


Figure 3-50: Voltage distortion at Lake depot – 120 kW fast charger in 2027 scenario

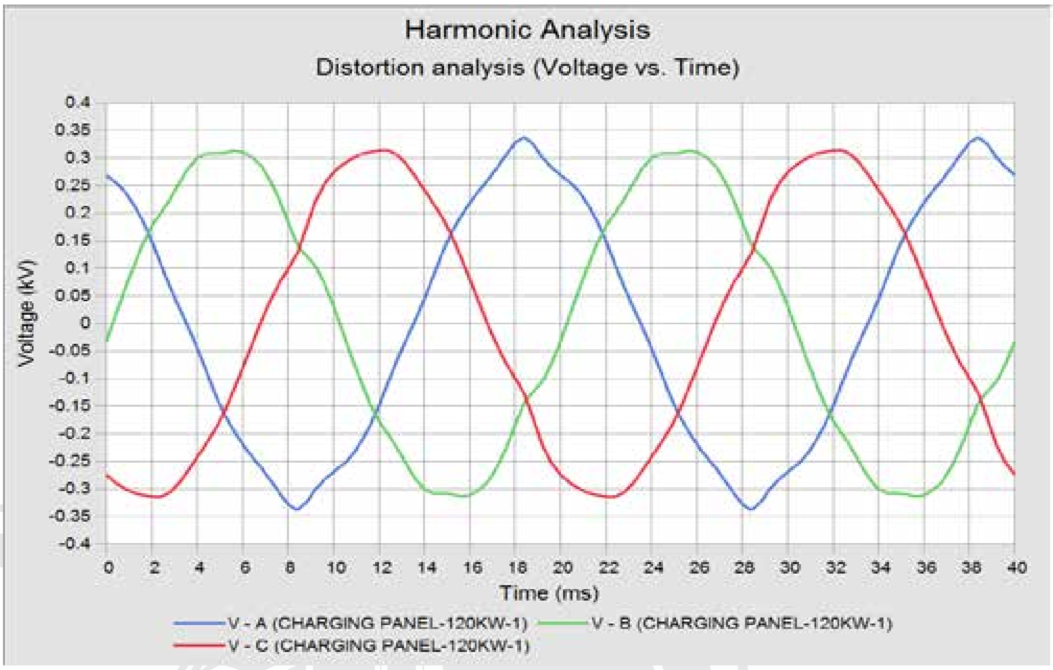


Figure 3-51: Voltage distortion at Lake depot – 120 kW fast charger in 2027 scenario

Referring to the results in the above figures, it has been observed that the voltage distortions are within the limits for 5th and 7th order harmonics on the LT side of the transformer in time domain and frequency domain.

3.6 Conclusions from the Load-flow Studies

The load-flow results of the 2022 scenarios and the PQM measurements have been compared and found to be in alignment. The scenarios studied for 2024 and 2027 assumed additional EVSE load besides normal load growth; and found voltage sags and harmonics beyond the acceptable limits. However, the EVSE load growth assumed for 2024 and 2027 could not be verified by relevant stakeholders. Hence, we did not estimate the mitigation measures in the absence of any accurate load growth estimates.

It is advised that when the EVSE load is enhanced in the bus depot, detailed planning studies may be undertaken to estimate the type and sizing of harmonic filters to be installed.

04

Observations, Analysis and Recommendations from the Study

4.1 Introduction

As stated already, for charging the EV, AC power from the grid is converted to DC and this process of AC to DC conversion creates harmonics and other impacts on the electric grid which are described below before ISGF present the analysis and observations from the study. General appreciation of the various issues that EV charging load can impact on the grid is necessary to understand the study results which are presented in the later sections in this chapter.

4.1.1 Waveform Distortion Due to EV Charging

For charging the battery of an EV, the alternating current (AC) from the electric grid need to be converted to direct current (DC). This conversion from AC to DC is done in the EVSE in case of DC chargers or by an onboard AC-DC convertor in the EV in case of AC charger. While AC is converted to DC, the sinusoidal waveform of AC is changed to pure sine wave. A complete charging cycle of an EV can be divided into two stages - constant current and constant voltage. From beginning of the charging till about 80% of the battery capacity (or state of charge – SOC), the charging takes place under constant current (CC) and after 80% SOC until full capacity, the charging is done at constant voltage (CV). EV chargers behave differently during these CC and CV stages from harmonic point of view. During CC stage they have low harmonic distortion but during CV stage the current waveform is more distorted. The level of current harmonic emission from EV charging depends on charger circuit topology, power level, the supply voltage distortion (background distortion), and the network impedance. The simplest diode rectifiers emit high level of current harmonics but with improvement in their circuits and control techniques, new generation of chargers have much less harmonic emission. A recently published work[9] reports significant variation in THD and individual harmonics current among 18 different EVs while charging with AC chargers and DC conversion through on-board chargers. The diversity of EVs and SOC of the batteries play significant role in cancellation of harmonics while aggregation of slow chargers. Fast chargers (usually more than 40 kW) have fixed location in the network compared with slow onboard chargers; hence it is easier to manage and control them.

4.1.2 Impact of Voltage Dips on EV Charging Stations

Voltage dips due to faults or switching actions in the electric grid affect a large geographic region and can propagate to the terminals of EV charging stations. These voltage dips may lead to abnormal operation of EV charging station and reduce the life cycles of EV batteries. The power quality (PQ) requirements for EV chargers are provided by SAE Standard J2894. According to this, the EV chargers must remain energized if the supply voltage drops until 80% of nominal for up to 2 seconds. Also, the EV chargers must ride-through a complete loss of voltage for up to 12 cycles. When the dip magnitude is below 80% but remains non-zero, is not explicitly covered by the standard. In this case, the standard

---

[9] Impact of Electric Vehicle Charging on the Power Grid - Shimi Sudha Letha and Math Bollen: https://www.diva-portal.org/smash/get/diva2:1530550/FULLTEXT02.pdf

suggests disconnecting the EV charger from the grid by undervoltage protection. Even with a requirement to maintain an EV charger in operation for some dip conditions, few works in the literature cover the impact of voltage dips in the type of equipment. The impact of the tripping of EV chargers is discussed in the standard. The main conclusion is that the tripping of EV chargers could result in the loss of a significant proportion of the total load, which could lead to unacceptable high voltages in the distribution feeders.

4.1.3 Impact of Load Imbalance

Electrical systems are designed for balanced load across the three phases. By balancing the loads, the current in each of the three branches is roughly the same and the resulting terminal voltages are also roughly the same. Unbalanced loading can result in currents within the neutral line. Because neutral lines tend to be undersized compared to the hot lines, these neutral currents can lead to excessive heating in extreme cases. Load imbalance also leads to voltage imbalance, which can be problematic for three-phase loads expecting equal phase voltages. Imbalance in a three-phase system is defined as the ratio of the magnitude of the negative sequence component to the magnitude of the positive sequence component, as defined in IEEE 1159-1995.

In a three-phase system, the increasing penetration of EVs has the potential to further imbalance the system. Either a single EV charger or a number of them are linked to the grid. The amount of the load is a factor in determining unbalance problems, but other elements, such as the source impedance, penetration level, and load distribution among phases, are also significant. According to a load flow study and harmonic analysis, the imbalance caused by EV chargers will have an impact on the packaged substation and transformers, which will then have an impact on the source feeder. Therefore, it is crucial for electric bus operators to balance the load in order to reduce harmonics in the network.

4.1.4 Impact of Fast Voltage Fluctuations from EV Charging on Light Flicker

EV charging could create fast voltage fluctuations, the magnitude of which depends on the transient charging current peak and impedance of the grid. This fast voltage fluctuation could create light flicker (repetitive change in light intensity) that human can perceive. The current peak depends on the SOC of the EV battery. The SOC of an EV battery coming for charging is unpredictable (it could vary from 20% or less to 60% or more depends on when the EV driver finds it convenient to charge) and therefore the current peak too is unpredictable. The current peak could reach up to 16 A in common household low voltage networks. The current patterns observed with fast charging and slow charging are different as more fluctuations were found in slow charging. Fast voltage fluctuations could be found at the beginning and at the end of the charging cycle. Similarly, battery status check, insulation test for output of DC circuit, on board battery protection, voltage checks, CAN[10] communication interval for charging current request, etc. can also create fast voltage fluctuations in both slow and fast charging.

4.1.5 Total Demand Distortion (TDD)

TDD is the harmonic current distortion of a system in percent of maximum demand load current, as defined in IEEE Std 519-2014. The maximum allowable TDD is determined by the ratio of the short

---

[10] Controller Area Network (CAN) is a serial communications protocol developed with in the automotive industry to allow a number of electronic units in a single vehicle to share essential control data. CHAdeMO, GB/T and Tesla standards use CAN protocol; while CCS uses power line communication (PLC).

circuit current at the point of common coupling to the to the average maximum demand load current for the system for the previous 12 months. Ideally, the harmonic distortion caused by a single consumer should be limited to an acceptable level at any point in the system; however, the prescribed levels for TDD establish the maximum allowable current distortion for a given system as per IEEE 519-2014. TDD have severe effects on electrical asserts like

- Transformers
- Power cables
- Relays, switchgears, and metering equipment
- Capacitors

4.1.6 Impact of EV Charging on Neutral Current and Protective Earth Current

The impact of EVSE on the neutral and protective earth (PE) currents and their consequences are described here. Single-phase rectifier in EV home chargers emanate third harmonic component in the neutral conductor. The pulse width modulation (PWM) switching methods are used to reduce the lower order harmonics in the system. The EVSE usually switch in the supraharmonics frequency range. Multiple chargers connected as residential loads, lead to an increase in the supraharmonics in the neutral and protective earth conductors[11]. This can have adverse effect on the operation of ground fault interrupters[12]. The increase in the leakage current (PE current due to supraharmonics) and triplen harmonics[13] can increase the RMS value of neutral current and cause false tripping of Residual Cuttent Device (RCDs). Neutral conductor can act as spreader of supraharmonics to the other loads connected in parallel with EV chargers. The amplitude beating in phase currents and voltages caused by the differences in the switching frequencies of same type of EVs connected in the same phase combined with supraharmonic emission can cause high leakage currents lading to tripping of the RCDs and charge circuit interrupting device in the charger.

4.1.7 Distribution Transformer Overloading due to EV Integration

The DC Fast Chargers (DCFCs) require high power connections. 50 kW to 240 kW DCFCs are widely installed in Europe, North America, and Japan etc and are becoming common in India as well. Unplanned installation of DCFCs can cause overloading of the distribution transformers (DTs). Aggregated charging pattern of the EV charging stations in a locality or town may be considered for planning of grid upgrade instead of the charging pattern of a specific station, because the aggregated charging pattern has higher impact on overall loading on the grid. The location of the EVSE changes the dynamic load flow characteristics of the distribution network sometimes that causes additional power losses, hence, additional power demand from DTs. Therefore, the overloading possibility of the DT is also increasing with increasing number of DCFC and EVs.

4.1.8 Impact of Temperature on EV Hosting Capacity

Driving conditions and ambient temperature are the factors that affect the energy requirement of the battery and vehicle. The regional difference in energy consumption pattern of the EVs enforce a risk

---

[11] The supraharmonics in neutral current are instantaneous summation of the three-phase currents

[12] The ground fault interrupters in EV are used to detect ground fault and disconnect the EVSE to protect the humans from shock in case of fault. The supraharmonics in neutral current are instantaneous summation of the three-phase currents.

[13] Tripen harmonics have frequencies in odd multiples of 3 such as 3, 9, 15, 21 etc. 3rd harmonics (150 Hz), 9th harmonics (450 Hz), 15th Harmonic (750 Hz) and so on have peculiar characteristics which make them very difficult to handle and mitigate.

to the operators if proper planning is not done. In India, ambient temperatures ranges between 10 to 45°C and their impact on the EV batteries cannot be neglected.

4.1.9 DC Offset

In addition to above power quality issues, several other PQ issues observed during this study at Pune and Kolkata. This includes phantom loading, load imbalance (resulting in current in neutral lines), and DC offsets - harmonic spectrum at the peak at 0 Hz (i.e., DC). This denotes a DC offset in the AC power flow. DC in AC networks can be detrimental. It could create transformer saturation and associated heating, additional stressing of insulation, and other adverse effects as per IEEE Standard 1159-1995. DC offset can be found in many of the charging events at various points throughout the cycle and in all three phases. The impact that this anomaly has on the distribution system should be included in all simulations of the EV chargers.

4.2 Harmonics Mitigation Techniques

Though all orders of harmonics are harmful to an electrical power system, the 5th and 7th order harmonics are most harmful to the electrical network. One of the solutions to mitigate these lower-order harmonics is to install harmonic filters. The harmonic filters are available in three categories:

1. Passive filters
2. Active filters
3. Hybrid filters

The passive filter has passive components like a resistor, inductor, capacitor. The active filter is designed using semiconductor devices like IGBTs. Hybrid filters are basically the combination of active and passive filters. In a hybrid filter, the passive components are used to mitigate the lower orders harmonics and the active components are used to mitigate higher orders harmonics.

The passive filters can be further categorized into tuned and de-tuned filters. The frequency of the 5th and 7th order harmonics is 250 Hz and 350 Hz respectively. The passive filters are generally used for mitigation of 5th and 7th order harmonics because the magnitude of the current of lower order harmonics is more than the magnitude of the current of higher-order harmonics. A tuned filter works on the principle of providing the least impedance path for one or two harmonic frequencies and has a tuning frequency, which is within ± 10 % of the harmonic frequency to be filtered.

Tuned filters of particular harmonics order carry more harmonic current as they offer low impedance to the dominant harmonics. Passive filter consists of two types - single tuned filter and double tuned filter.

4.3 Observations and Analysis of the Findings from PQM Readings

4.3.1 Pune Study

The power quality monitoring study was conducted at **Pune bus depot** for the period **1st August 2021 to 9th August 2022.** The power quality standard EN50160 is used as the primary reference for the PQ study and analysis; and the key findings are presented below.

- **Voltage Variations** measured for the complete span of time (01 August 2021 to 09 August 2022) are within the limits prescribed in EN50160

- **THD and Individual Harmonics** measured for the complete span of time are within the limits prescribed in EN50160
- **Voltage Imbalance** measured for the complete span of time are within the limits prescribed in EN50160
- **Frequency and Signalling Voltage** measured for the complete span of time are within the limits prescribed in EN50160
- **Flicker (Plt)** measured for the complete span of time are within the limits prescribed in EN50160
- **Voltage Sags** measured for complete span of time are within the limits according to EN50160; however, during the one year of measurement, a total of 65 sags (out of 401 sags recorded) are below 60% of rated voltage. As per Semi F47[14], these sags have higher severity level and have the potential to damage electronic and semiconductor devices. These voltage sags were induced in the electrical networks from upstream, which need investigation. It is recommended to install Class A online Power Quality Monitoring system to continuously monitor voltage sags so that correlation can be established in case of equipment/component failures occur. It is recommended to have continuous online monitoring system and perform regular analysis for a longer period of time till the installed load increase to the planned load (maximum)
- The load profile observed at the PQ measurement point is less than 50% of the total capacity, however if the loading increases in future the Power quality may degrade.

Some of the important events are presented below.

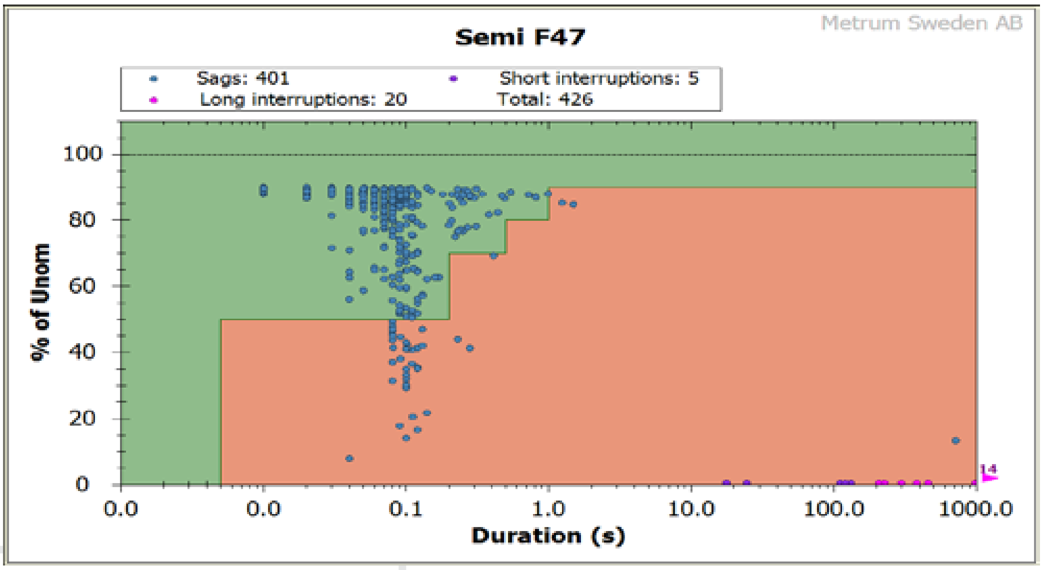


Figure 4-1: Recorded voltage sags at Pune bus depot as per Semi F47

The above figure depicts the total 401 sags recorded during the span of one year where 65 sags are in the brown area having potential to damage the semiconductor devices.

---

[14] Semi F47 is Semiconductor Processing Equipment Voltage Sag Immunity Standard which explains the severity of voltage sags with respect to its effect on semiconductor devices

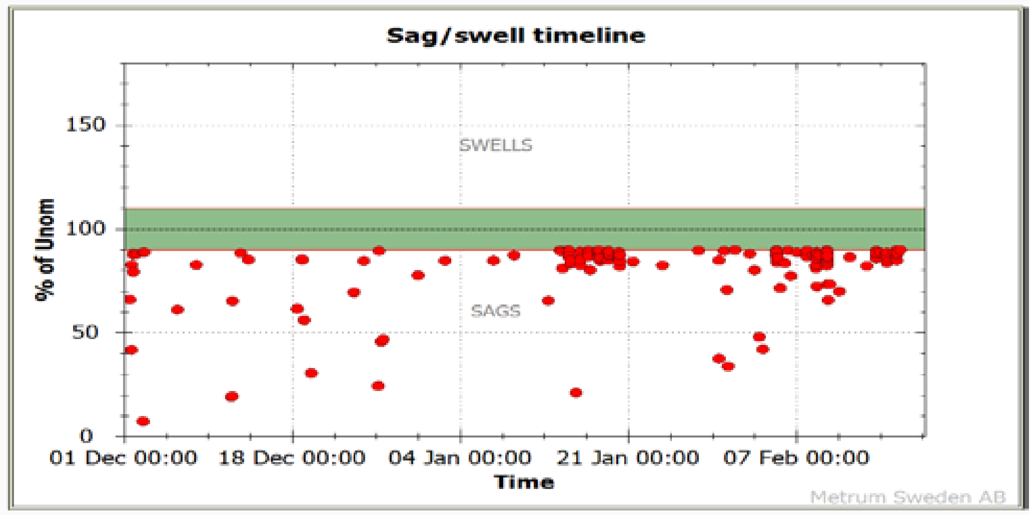


Figure 4-2: Voltage sags recorded

Above figure depicts all the events of sags recorded for the duration, no swells were recorded during the period of study. The recorded sags have originated from the transmission grid. Voltage sags could occur due to short circuits in HV grids, MV grids and LV grids.

Summary of the voltage transients and duration recorded at Pune from September 2021 to July 2022 is plotted below.

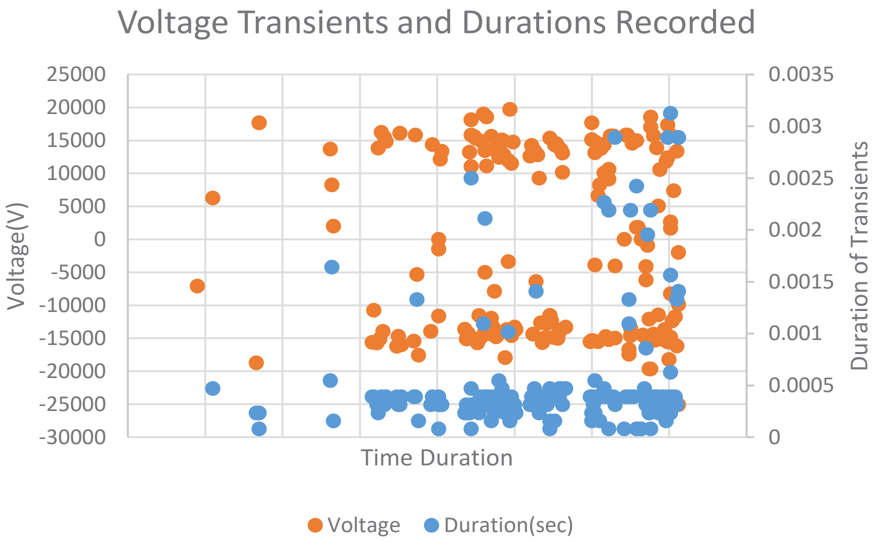


Figure 4-3: Transients recorded from September 2021 to July 2022

Table 4-1: Long interruption events recorded at Pune

Sl No	Date	Time	Phase	Duration (sec)
1	14-01-2021	07:54:59	3	193
2	09-02-2022	06:54:42	3	11550
3	02-03-2022	05:59:25	3	4484
4	12-04-2022	09:46:39	2	1753
5	20-05-2022	12:49:34	2	1349

6	23-05-2022	06:49:40	2	382
7	09-06-2022	02:50:00	3	1519
8	09-06-2022	03:59:26	1	2681
9	24-06-2022	07:40:01	3	19670
10	26-06-2022	10:36:13	2	2789
11	28-06-2022	03:56:35	3	225
12	29-06-2022	12:00:07	3	1529
13	29-06-2022	10:58:42	2	459
14	04-07-2022	12:18:36	1	2186
15	07-07-2022	12:27:01	3	206
16	09-07-2022	10:40:08	3	1697
17	13-07-2022	12:31:52	3	1106
18	14-07-2022	01:00:53	3	1105
19	20-07-2022	01:00:41	3	978
20	22-07-2022	09:44:04	1	298
21	26-07-2022	12:52:35	3	2985
22	06-08-2022	07:32:27	2	5478

These interruptions may be corelated with utility data of faults and tripping.

4.3.2 Kolkata Study

The power quality monitoring study was conducted at **Lake depot, Kolkata** from **December 2021 to August 2022**. The power quality standard **EN50160** is used for the PQ study and analysis. The key observations are presented here.

- **Rapid Voltage Change (RVC)** observed for complete span of time are outside the limits prescribed by EN50160 standards. The RVCs observed have higher severity level and have the potential to damage electronic and semiconductor devices. As most problems are caused by intermittent reoccurring faults, it is important to look at power quality measurements from a not-too-distant measurement point that has been recorded during the time the customer experienced the equipment failure. In the best case a voltage dip or rapid voltage change can be seen on such measurement, which can be correlated with the equipment failure.
- **Voltage Variations** recorded have also failed as per EN50160 for the complete span of time; it is the higher loads that was responsible for voltage variations
- **THD and Individual Harmonics** recorded are within the limits as per EN50160 standard for the complete span of time
- **Voltage Unbalance** measured are within the limits as per EN50160 for the complete span of time
- **Frequency and Signalling Voltage** recorded are within the limits prescribed in EN50160 for the complete span of time
- **Flicker (Plt)** recorded are within the limits prescribed in EN50160 for the complete span of time
- **Voltage Sags** measured for complete span of time are within the limits according to EN50160. However, during the study period a total of 28 sags out of 130 recorded sags are below 60% of rated voltage. As per Semi F47, these sags are having higher severity level and have the potential to damage electronic and semiconductor devices. These sags are being induced in the electrical networks from upstream.
- **THD** measured are within the limits prescribed in EN50160 for the complete span of time limits

- The load profile observed at the PQ measurement point is less than 50% of the total capacity, however if the loading increases the power quality may degrade
- It is recommended to have continuous online monitoring system and perform regular analysis for a longer period till the installed load increase to the planned load (maximum). It is also recommended to monitor the voltage variations very closely and if they are increasing in the course of time, some mitigation methods shall be adopted like installation of automatic tap changer controls

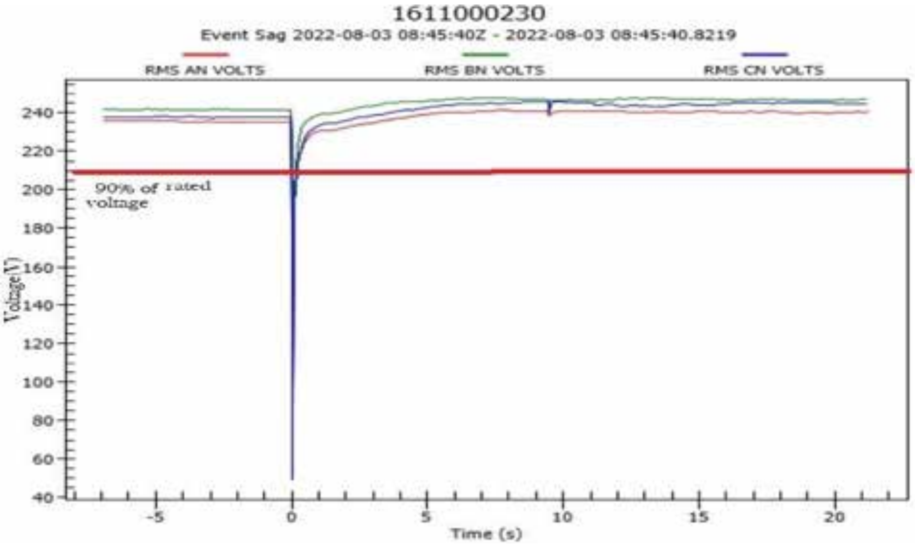


Figure 4-4: Voltage sag at Lake depot - 21% of Unom phase 1

The above figure depicts the voltage sag of 21% of Unom recorded for the month of August 2022 at Lake depot.

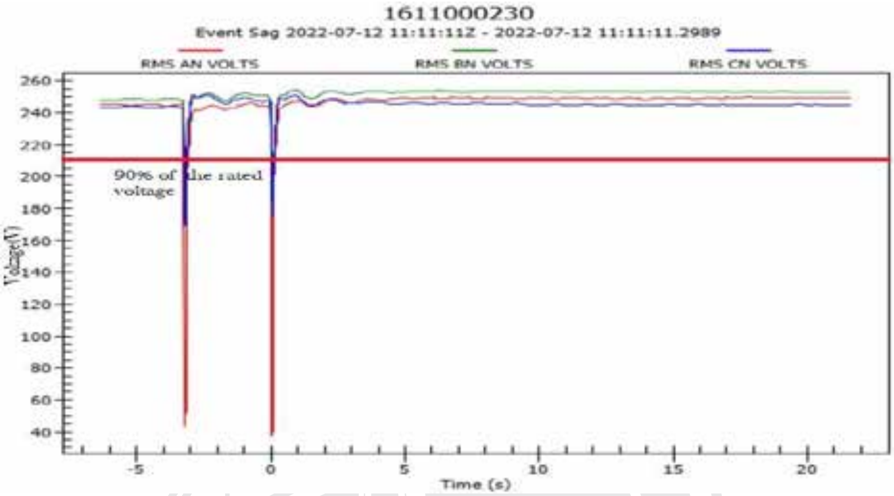


Figure 4-5: Voltage sag at Lake depot - 15% of Unom phase 1

The above figure depicts the voltage sag of 15% of Unom recorded for the month of July 2022 at Lake depot.

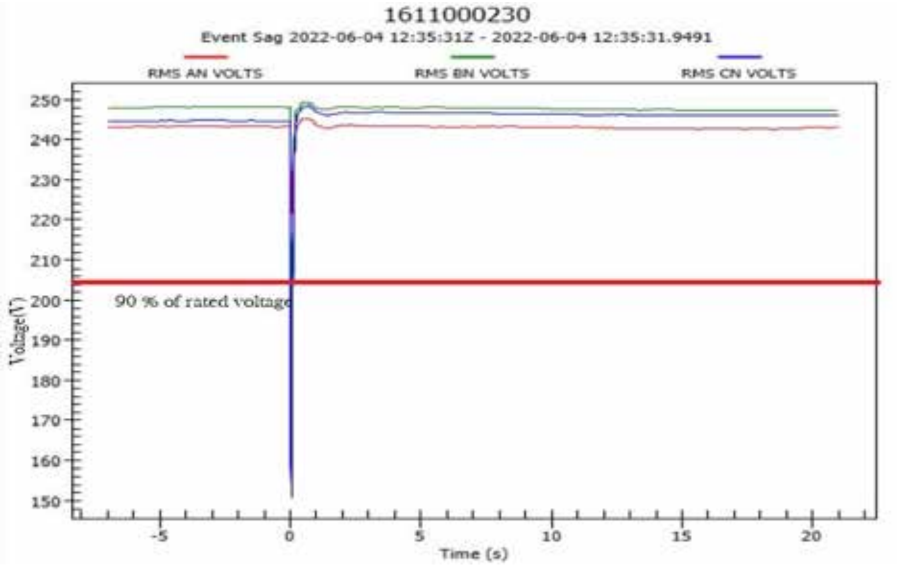


Figure 4-6: Voltage sag at Lake depot - 62% of Unom phase 3

The above figure depicts the voltage sag of 62% of Unom recorded for the month of June 2022 at Lake depot.

The below table shows the recorded voltage sag of ≤ 60 % from December 2021 to August 20222 except for the January 2022, February 2022 and March 2022 where no voltage sag of ≤60% were recorded.

Table 4-2: List of sags less than 60% of Unom recorded at Lake depot, Kolkata

Sl No	Time	Voltage	% Of Unom	Direction
1	02-12-2021	100.51	41.136684	Upstream
2	02-12-2021	109.47	44.718426	Upstream
3	02-12-2021	145.70	60.333969	Upstream
4	24-04-2022	93.798	39.142948	Upstream
5	24-04-2022	117.93	49.383655	Upstream
6	01-05-2022	130.79	55.320732	Upstream
7	01-05-2022	134.07	55.425243	Upstream
8	01-05-2022	134.08	56.498737	Upstream
9	09-05-2022	16.253	6.8168334	Upstream
10	12-05-2022	111.93	47.662288	Upstream
11	12-05-2022	113.48	47.889541	Upstream
12	12-05-2022	119.92	49.689037	Upstream
13	12-05-2022	115.19	48.624557	Upstream
14	12-05-2022	127.90	53.896690	Upstream
15	12-05-2022	130.97	54.396713	Upstream
16	04-06-2022	150.66	60.683601	Upstream
17	12-07-2022	43.806	17.902435	Upstream
18	12-07-2022	37.401	15.287155	Upstream
19	17-07-2022	86.645	35.571647	Upstream
20	17-07-2022	92.753	37.390907	Upstream

21	22-07-2022	106.85	44.862171	Upstream
22	03-08-2022	49.601	21.079986	Upstream
23	03-08-2022	49.074	20.676002	Upstream
24	03-08-2022	52.889	21.947425	Upstream
25	08-08-2022	103.06	42.923549	Upstream
26	08-08-2022	92.050	37.399818	Upstream
27	09-08-2022	102.03	43.192146	Upstream
28	09-08-2022	99.708	41.340290	Upstream

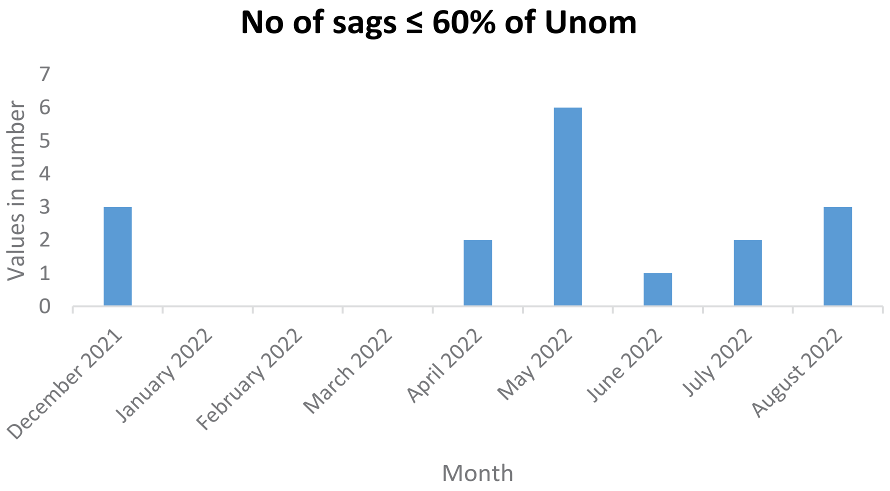


Figure 4-7: Voltage sags

The above figure shows the voltage sags of 60% or less from December 2021 to August 2022. No sags were recorded in the months of January 2022, February 2022 and March 2022.

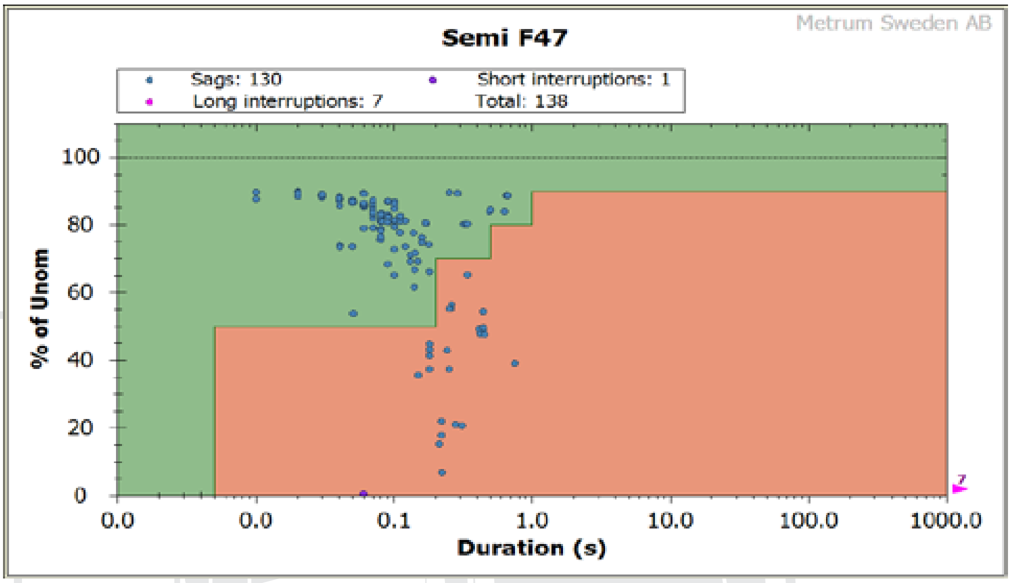


Figure 4-8: Recorded voltage sags at Lake depot as per Semi F47

Semi F47 is Semiconductor Processing Equipment Voltage Sag Immunity standard which explains the severity of sags with respect to its effect on semiconductor devices. The above figure depicts a total 130 sags recorded during the study period where 28 sags are in the brown area having potential to damage the semiconductor devices connected to the network.

Some of the Rapid Voltage Changes (RVC) recorded are given below.

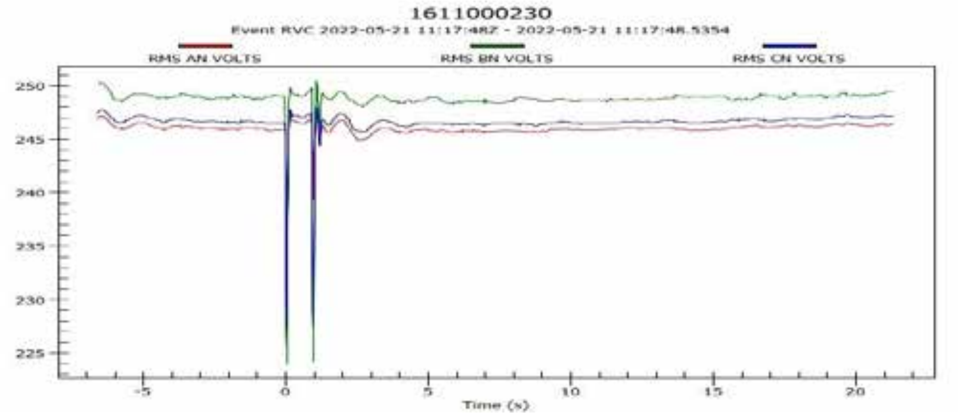


Figure 4-9: RVC recorded for 1 seconds for phase 3 on 05 May 2022

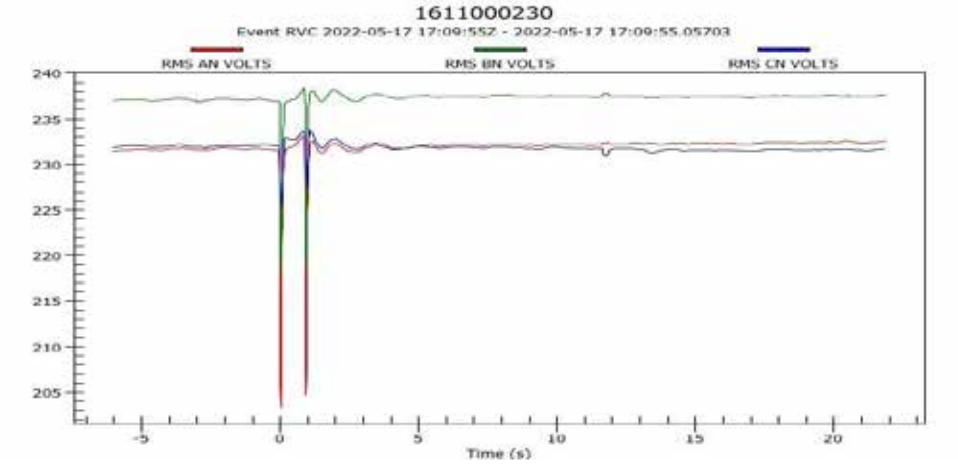


Figure 4-10: RVC recorded for 0.98 seconds for phase 2 on 17 May 2022

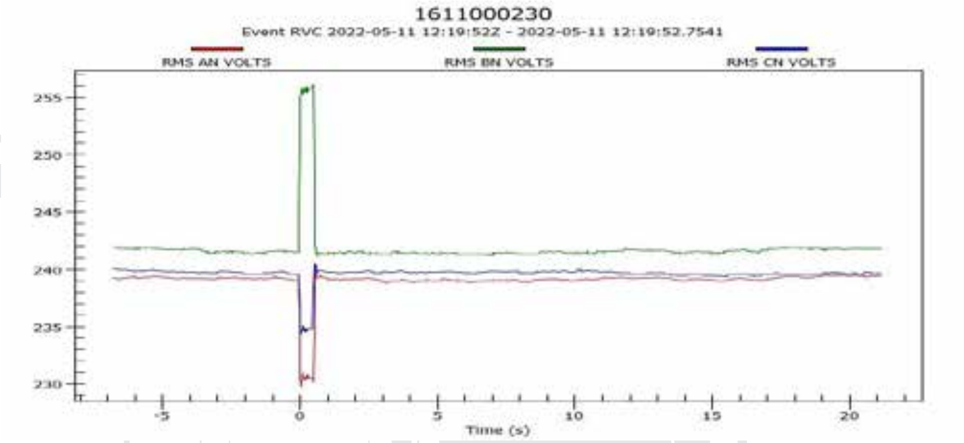


Figure 4-11: RVC recorded for 1.11 seconds for phase 2 on 11 May 2022

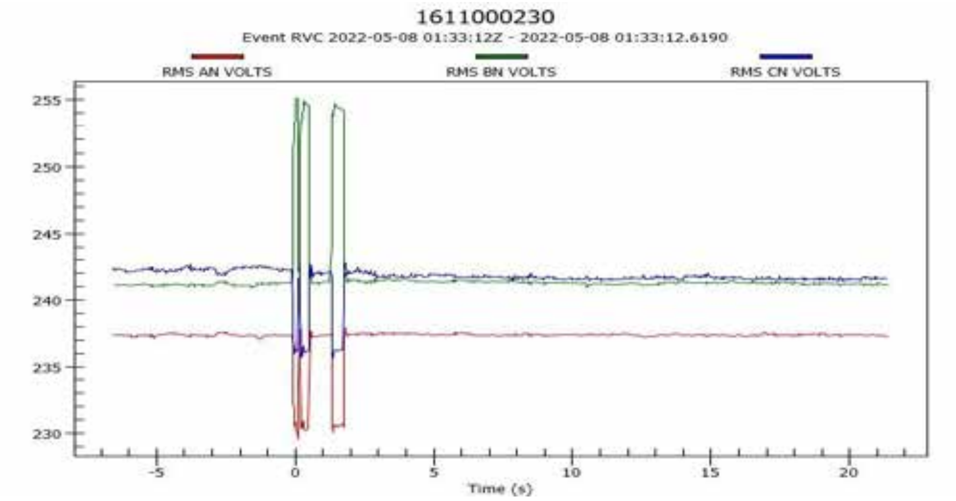


Figure 4-12: RVC recorded for 2.31 seconds for phase 2 on 08 May 2022

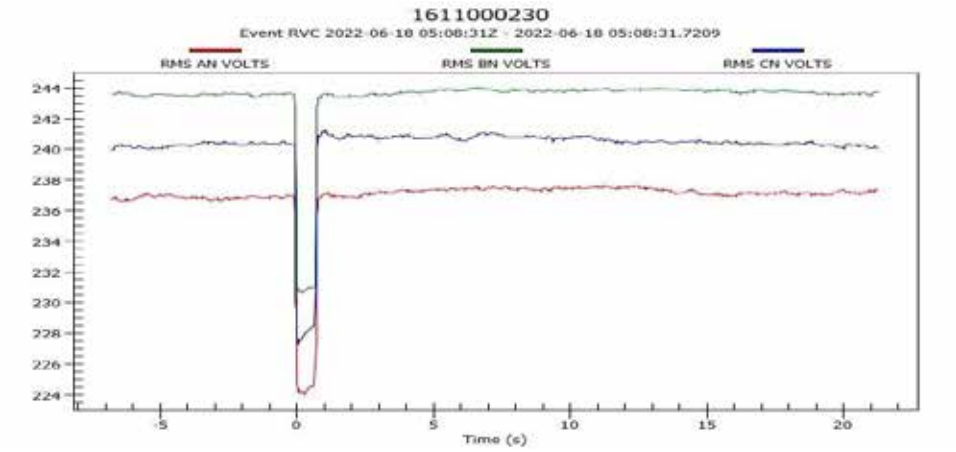


Figure 4-13: RVC recorded for 1.24 seconds for phase 1 on 18 June 2022

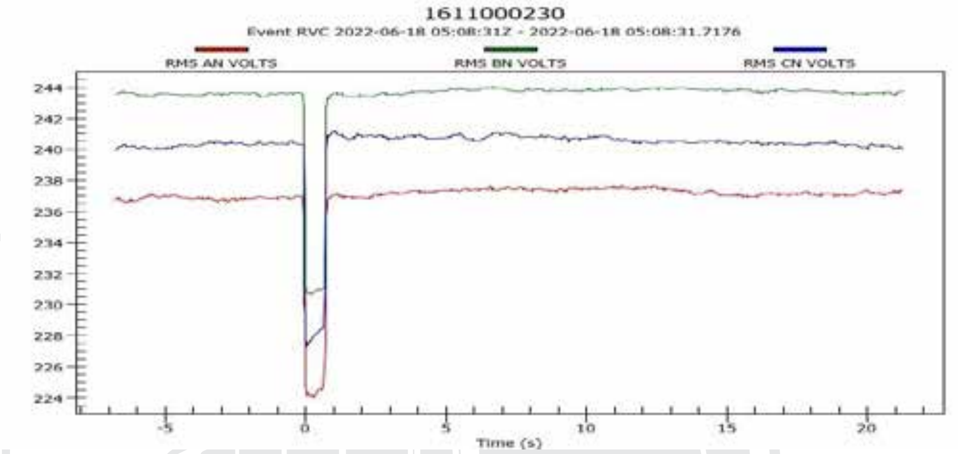


Figure 4-14: RVC recorded for 1.25 seconds for phase 2 on 18 June 2022

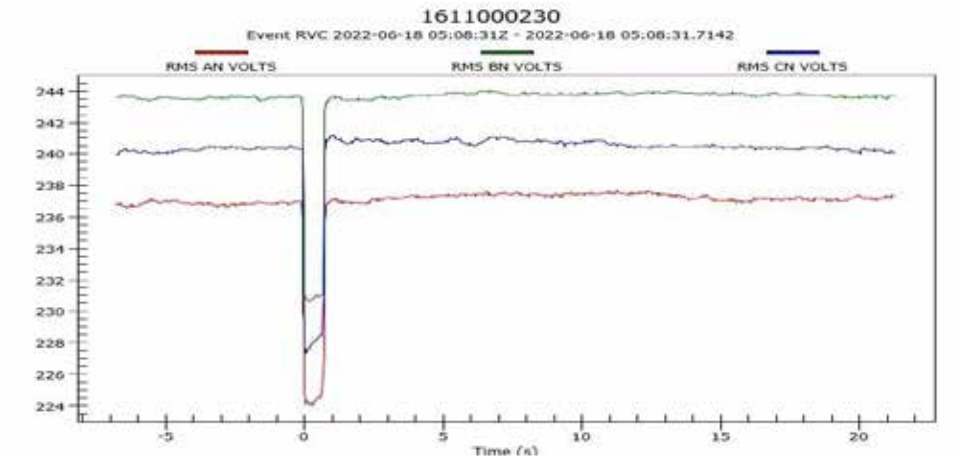


Figure 4-15: RVC recorded for 1.26 seconds for phase 3 on 18 June 2022

Table 4-3: List of Rapid Voltage Changes recorded at Lake depot, Kolkata

Sl No	Time	Duration	Voltage
1	08-12-2021	1.4615	245.58
2	22-12-2021	1.1003	242.51
3	22-12-2021	1.1803	244.85
4	01-01-2022	1.1184	242.26
5	01-01-2022	1.1085	243.05
6	01-01-2022	1.1084	244.83
7	08-05-2022	2.3171	255.14
8	11-05-2022	1.1104	256.06
9	17-05-2022	0.9843	238.34
10	21-05-2022	1.0080	248.11
11	14-06-2022	0.8791	243.12
12	18-06-2022	1.2436	237.16
13	18-06-2022	1.2536	243.66
14	18-06-2022	1.2637	241.19
15	10-07-2022	1.009	248.17
16	10-07-2022	1.1307	247.44
17	10-07-2022	1.1408	251.36
18	10-07-2022	1.1408	248.13
19	29-07-2022	1.1099	244.05
20	02-08-2022	1.1597	249.52

The above Table shows the deviated voltage from 230 V from the month of December 2021 to August 2022 except February 2022, March 2022 and April 2022 as no voltage deviations were recorded.

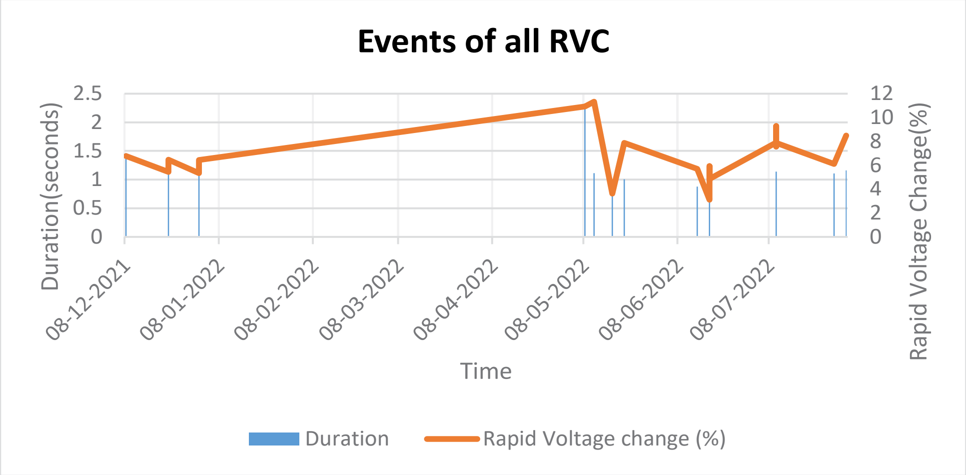


Figure 4-16: Events of RVC from December 2021 to August 2022

4.4 Recommendations

Overall, the power supply and power quality parameters observed at Pune and Kolkata are satisfactory. However, following points require careful study and investigation.

- In Pune during the study period, 65 voltage sags measured were below 60% of the rated voltage which is harmful to all electronic and semiconductor devices. It was found that these voltage sags emanated from the transmission grid
- In Kolkata, during the study period of 9 months, several Rapid Voltage Change (RVC) were observed and all of them were outside the limits prescribed by EN50160 standards. The RVCs observed have higher severity level and have the potential to damage electronic and semiconductor devices. Besides RVC, other Voltage Variations recorded in Kolkata were also beyond the limits prescribed in EN50160. Perhaps, overloading of the network caused these voltage variations.

It is recommended to install Class A online Power Quality Monitoring system to continuously monitor voltage sags, RVCs and other parameters so that correlation can be established in case of equipment/component failures occur. As most problems are caused by intermittent reoccurring faults, it is important to look at power quality measurements from a not-too-distant measurement point that has been recorded during the time the customer experienced the equipment failure.

Specific recommendations to different stakeholders are given below.

4.4.1 Recommendations for DISCOMs

For HT (11kV/22kV/33kV) connections to Bus Depots and other Public Charging Stations:

- The detailed engineering drawings along with equipment sizing calculations (of the electricity distribution arrangements within the Bus Depot/Public Charging Stations including the Chargers) must be verified and approved by the DISCOMs before sanctioning HT connections.
- All electrical equipment installed inside the Bus Depots and Public Charging Stations must conform to relevant BIS and IEC standards which must be checked by the DISCOM Engineers.

- The Site Engineer in-charge of the charging stations should coordinate with the DISCOM Engineer at the respective substations from where the HT connection is given; and must have minimum trainings on operation of numerical relays and protection systems.
- Where ever possible, the DISCOM must explore the possibility of providing a dedicated feeder to these kinds of facilities which is a totally new kind of load on the grid.
- Power Quality Meters (which can record voltage and harmonic profiles) must be installed in all EV Charging Stations and the history of the recordings must be maintained for a mutually agreed time period.

4.4.2 Recommendations for Electric Bus Operators

- To the extent possible, should minimize the concentration of chargers at one location. This will help in having chargers in multiple bus depots which could service buses in case there are any faults in one location
- Distributing the charging load on different locations (feeders) will reduce the harmonics effects on the grid equipment
- The packaged sub-stations (PSS) and Bus Chargers must be located far away from the passenger boarding locations
- Standard Operating Procedures (SOP) must be prepared and get it approved by the respective DISCOMs
- Load profile of the PSS should be recorded and must be maintained for a mutually agreed time period
- The Site Engineers and Operators in the Charging Stations must be given training on PSS, numerical relays and protection scheme
- Staff should be trained in electrical safety and follow standard operating procedures for charging and handling the EV batteries
- Earthing for the installations to be carried out as per recommended standard, earth resistance to be maintained within recommended limits and body of all equipment to be connected with earth at two points
- Charging stations in depots should have proper fire extinguishers and smoke detectors installed. There should also be a clear evacuation procedure in case of a fire.
- Staff should be provided with appropriate personal protective equipment (PPE). There should be a clear signage and markings to indicate the high voltage areas and staff should be trained to avoid contact with live electrical components.
- Visual checking of the vehicles and electrical installations should be carried out in a predetermined frequency
- It is a practice that in case of transformer or a cable faults, no re-energization is carried out without ensuring that the fault is cleared and necessary recommissioning tests done. If not done, it could damage the equipment.
- Chargers must be installed on pedestals, high enough to protect from flooding. Also, should ensure that water does not go inside the chargers which could lead to faults.
- Preferably, rain guard/ canopy be placed on top of the EV chargers, at a height (to cover the charging receptacle of bus) to eliminate hazards from rain water (and sun light) while performing charging activity during rainy seasons.
- Mechanical wheel stopper for bus should be installed in between charger and relative position of bus, to avoid any accidental dashing, during placement of the vehicle for charging

- Adequate illumination of the charging area to be provided for the charging operation when inadequate natural light is present
- Distinct bay marking for parking of the electric bus to be provided, at bus depots, on the floor preferably with fluorescent paint.
- CCTV should be installed to monitor the charging area 24x7. Unauthorised access should be denied in the charging area.
- In case of an emergency there should be clear protocols in place to shut down the charging equipment and isolate the battery

4.5 Electric Bus Deployment Scenario in India

As of October 2022, total number of electric buses deployed in India is 2517 against a total sanctioned 6740 electric buses by Department of Heavy Industries (DHI) under FAME I and FAME II as mentioned in the Table below.

Table 4-4: State/UT-wise List of Sanctioned and Deployed Electric Buses in India

Sl No	**State/UT**	**No. of electric bus es Sanctioned by DHI (FAME I + FAME II)**	**No. of electric bus es Deployed**		
			FAME I	**FAME II**	**Total**
1	Jammu & Kashmir	190	40	-	40
2	Uttar Pradesh	640	40	521	561
3	Maharashtra	1110	95	659	754
4	Himachal Pradesh	175	75	-	75
5	Assam	115	15	-	15
6	West Bengal	230	80	7	87
7	Madhya Pradesh	380	40	-	40
8	Telangana	365	40	-	40
9	Uttarakhand	80	-	20	20
10	Tripura	50	-	-	
11	Odisha	50	-	10	10
12	Chhattisgarh	50	-	-	
13	Andhra Pradesh	350	-	5	5
14	Tamil Nadu	525	-	-	
15	Kerala	250	-	-	
16	Karnataka	400	-	91	91
17	Goa	150	-	50	50
18	Dadra and Nagar Haveli	25	-	19	19
19	Gujarat	900	-	329	329
20	Bihar	25	-	25	25
21	Delhi	400	-	306	306
22	Rajasthan	150	-	-	
23	Haryana	50	-	-	
24	Chandigarh	80	-	50	50
Total		**6740**	**425**	**2092**	**2517**

As per Convergence Energy Services Limited (CESL), the electric bus potential in India is 66,000 by 2030. Presently, CESL intend to procure 5,450 electric buses under their Grand Challenge Program for five cities (Delhi - 1500, Surat -150, Bengaluru - 1500, Hyderabad - 300, Kolkata - 2000) on Gross Cost Contract basis with guaranteed run of 70,000 km per year. Ministry of Housing and Urban Affairs intend to deploy 20,000 electric buses in 100 smart cities. There is also a program to convert 250,000 school buses into electric buses on fast track.

Although, there is no official target for the number of electric buses in India by 2030, ISGF feel it safe to assume following numbers from the perspective of power requirement and electric grid planning to support electric mobility in India.

Table 4-5: Forecasted electric buses

Scenario	No. of electric buses Estimated	Annual Electricity Requirement* (in Billion kWh)
By 2025	50,000	4.2 BU
By 2030	100,000	8.4 BU
By 2040	500,000	42 BU
* Assuming 70,000 km/year running at the average rate of 1.2 kWh/km		

The estimated annual electricity consumption for electric buses is a very small portion of the annual electricity generation in India. During FY 2021-22, India generated 1313.47 BU; and it is estimated to double by 2030. Although the energy requirement of 8.4 BU for electric buses is only a small fraction of the total power generation, it could create huge power demand on the distribution grid at several places. The grid planning by electric utilities must be in coordination with electric bus deployment plans of various transport companies. Since the new models of electric buses are expected to have batteries that can be charged at 1C[15] rate or faster; and the average battery sizes are expected to be 200 kWh to 250 kWh, the capacity of the EVSEs at bus depots will be 200 kW or higher. This scenario requires MW-scale power connections in thousands of bus depots across the country. In most parts of India, the summer peak-load is experienced during night hours due to the cooling load which is constantly increasing. The charging load from the electric buses will also be maximum during night hours. This situation underscores the need for distribution grid planning and strengthening in close coordination with transport agencies involved in electrification of transportation.

4.6 Standards for EVSE and Batteries

India has emerged as a leader in developing indigenous standards for EVSE. Based on the request by ISGF in 2016, Bureau of Indian Standards (BIS) constituted Electrotechnical Division (ETD) 51 Committee for preparation of Indian standards for EVSE. ETD 51, chose to adopt the IEC standards as the primary standards for EVSE in India. BIS has already issued IS 17017 Part 1 in 2018; and several accompanying standards published in the last four years as listed in the table below.

Table 4-6: Indian Standards for EVSE (Status as of October 2022)

Indian Standards	Description	Publishing Year
IS 17017 Series of Standards	**Primarily based on IEC 61851; IEC 62196** **IS 17017 recommends AC Type-2 including system A and system C chargers**	
IS 17017-Part 1	General Requirements and Definitions of EVSE	Published in 2018
IS 17017-Part 2-1 IS 17017-Part 2-2 IS 17017-Part 2-3	Adapted from IEC 62196 - Part: 1, Part: 2, Part: 3 Standards for the Plugs, Socket Outlet, Vehicle Couplers and Vehicle Inlets	Published in 2020
IS 17017-Part 2-6	Light EV DC Vehicle Connector/ Inlet	Published in 2021

---

[15] If a battery can be fully charged in 1 hour, it is a 1C battery; if takes 2 hours to charged then it is a 0.5C; and if it can be charged in 30 minutes then it is 2C battery.

IS 17017-Part-6	LEV DC Connector	Published in 2021
IS 17017-Part 21 Electromagnetic Compatibility (EMC)	Electric Vehicle Requirements for Conductive Connection to an AC/DC supply	Published in 2019
IS 17017-Part 21-1	On-Board Charger	
IS 17017-Part 21-2	Off-Board Charger	
IS 17017-Part 22-1	AC Charge Point for Light Electric Vehicle	Published in 2021
IS 17017 Part 22-2	Combined Charge Point	Under development
IS 17017-Part 23	DC Electric Vehicle Charging Station (Adapted from IEC 61851-23)	Published in 2021
IS 17017-Part 23-1	H-category/ electric bus es require generally around 100 kW DC Supply. DC Electric Vehicle Charging Station with Connection Systems	Draft ready
IS 17017-Part 23-2	L-category/ Light EV DC supply. (2W between 1 & 2 kW; 3W between 3 & 5 KW). DC EVSE where Protection Relies on Electrical Separation	Under development
IS 17017-Part 23-3	M-category/ EV cars require generally up to 50 kW DC supply. DC EVSE	Draft ready
IS 17017-Part 24	Digital Communication between a DC EV charging Station and An Electric Vehicle for Control of DC Charging	Under printing
IS 17017-Part-25	Light EV DC Charge Point	Published in 2021
IS 17017-Part 3	Communications for EV infrastructure management	Under development
IS 17017-Part 3-1	EVSE to the charge point aggregator	Draft ready
IS 17017-Part 3-2	Charge point aggregator to utility central management system	Under development
IS 17017-Part 4	Connection systems	Draft ready
IS 17017-Part 4-1	General requirements, comprising clauses of a general character that apply to all four modes of EV charging	Draft ready
IS 17017-Part 4-2	Dimensional compatibility and interchangeability requirements for AC pin and contact-tube accessories	Draft ready
IS 17017-Part 4-3	Dimensional compatibility and interchangeability requirements for DC and AC/DC pin and contact-tube vehicle couplers	Draft ready
IS 17017-Part 4-4	Light EV (AC & DC) connection systems	Under development
IS 17017-Part 4-5	Combined connection systems for medium power DC (Type-2; configuration DD)	Under development
IS 17017-Part 4-6	Heavy EV connection systems (AC+DC combined connection system and automated high-power DC connection systems)	Under development
IS 17017-Part 5	Grid connectivity and EVSE networks	Draft ready
IS 19367	Electric Vehicle Battery Swap System – Part 4 Light Electric Vehicles – Section 2 Connection Systems	Draft ready

IS 19366	Electric Vehicle Battery Swap System – Part 4 Light Electric Vehicles – Section 1 Guidelines and pack dimensions	Draft ready
IS 17180	Electric Vehicle battery swap system – Part 4 Light EVs – Section 3 Communication Protocol	Draft ready
ETD 51	Requirements for Light Electric Vehicles (LEV) Battery Swap Systems (BSS)	Draft ready
IS/ISO 15118	Communication between EV and EVSE	6 volumes published in 2019

ETD 51 comprises of members from industry, utilities, government institutions, academia, and research bodies. Remaining standards are expected to be completed in 2023.

The global standard for EVSE and battery safety are listed in the Table below:

Table 4-7: Global Safety Standards for EVSE and Batteries

Sl No	Reference	Title
1	ISO 6469-3	Specifications for batteries and high-voltage systems on electric vehicles.
2	ISO 6469-4	Specifications for batteries and high-voltage systems on electric vehicles.
3	ISO/DIS 21498	Specifications for high-voltage systems on electric vehicles.
4	ISO 12405	Specifications for lithium-ion battery packs and systems.
5	ISO 21782	Specifications for electric propulsion components (motor, inverter, DC-DC converter) and their combinations (motor system) for electric vehicles.
6	SAE J1766	Recommended practice for electric and hybrid vehicle battery systems integrity.
7	SAE J2929	Safety standard for electric and hybrid vehicle propulsion battery systems using lithium-based rechargeable cells.
8	SAE J2344	Guidelines for electric vehicle safety.
9	SAE J2464	Recommended practices on electric and hybrid electric vehicle rechargeable energy storage system (RESS) safety and abuse testing.
10	UL 2580	Specifications and stress tests for large electric vehicle batteries aiming to mitigate the risk of fire and electrical hazards.
11	SAE J2910	Recommended practice for design and testing hybrid electric or fully electric trucks and buses for electrical safety.
12	SAE J3004	Standardisation of battery packs for fully electric and hybrid trucks and buses.
13	SAE J3125	Integration of battery pack systems in bus electrification.
14	IEC 61851	Series of standards covering safety-related specifications on the charging station, the electromagnetic compatibility and the communication between vehicle and charger (including vehicle to grid functionality) (IEC, 2017a; IEC, 2017b; IEC, 2018; IEC, 2014c; IEC, 2014d; IEC, 2020a).

The important parameters from the rules issued by Ministry of Power for Public Charging Stations (PCS), CEA rules and other relevant standards and regulations are summarised in **Appendix VI**.

4.7 Standard Operating Procedures for EVSE in Bus Depots

As already mentioned, thousands of bus depots would soon require MW-scale electricity connections to support charging of electric bus fleets. In order to install high-capacity chargers and ensure its safe operation and maintenance, it is important to have a set of standard operating procedures (SOP) which need to be followed by all relevant stakeholders – electric utilities, transport companies, municipal corporations, fleet operators, electric bus OEMs and EVSE OEMs.

A draft SOP for EVSEs in bus depot is given at **Appendix VII**. This is an initial draft of an SOP for EVSE installation, operation and maintenance in bus depots and other public charging stations. The users may like to fine-tune this with respect to their specific set of chargers and needs.

Appendix I: Number of Buses Allotted Under FAME II

Sl No	State	Name of City	Category	Sub Category	Electric bus Allocated	Sate Total
1	Andhra Pradesh	Visakhapatnam	Million Plus	Million Plus and Smart	100	300
2		Vijayawada	Million Plus	Million Plus	50	
3		Amravati	Other City	Capital and Smart	50	
4		Tirupati	Other City	Smart	50	
5		Kakinada	Other City	Smart	50	
6	Assam	Guwahati	Special Category	Smart	50	100
7		Silchar	Special Category	City from Special Category State	25	
8		Jorhat	Special Category	City from Special Category State	25	
9	Bihar	Patna	Million Plus	Million Plus, Capital and Smart	25	25
10	Chhattisgarh	Raipur	Million Plus	Million Plus, Capital and Smart	50	50
11	Dadra & Nagar Haveli	Dadra & Nagar Haveli (Silvasa)	Another city	Capital and Smart	25	25
12	Delhi	New Delhi (DTC)	Four Million Plus	Million Plus, Capital and Smart	300	300
13	Gujarat	Ahmedabad	Four Million Plus	Million Plus and Smart	300	550
14		Surat	Four Million Plus	Million Plus and Smart	150	
15		Vadodara	Million Plus	Million Plus and Smart	50	
16		Rajkot	Million Plus	Million Plus and Smart	50	
17	Haryana	Gurugram	Other City	Setellite Town	50	50
18	Himachal Pradesh	Shimla	Special Category	Capital and Smart	50	100
19		Hamirpur	Special Category	City from special Category State	50	
20	Jammu & Kashmir	Srinagar	Special Category	Million Plus, Capital and Smart	100	150
21		Jammu	Special Category	Capital and Smart	50	
22	Karnataka	Bengaluru	Four Million Plus	Million Plus, Capital and Smart	300	350
23		Hubli-Dharwad	Other City	Smart	50	
24	Kerala	Trivandrum	Million Plus	Million Plus, Capital and Smart	100	250
25		Kochi	Million Plus	Million Plus and Smart	100	
26		Kozhikode	Million Plus	Million Plus	50	
27	Maharashtra	BEST Mumbai	Four Million Plus	Million plus, Capital	300	725
28		Pune	Four Million Plus	Million Plus and Smart	150	

29		Navi-Mumbai	Million Plus	Million Plus	100	
30		Nagpur	Million Plus	Million Plus and Smart	100	
31		Nashik	Million Plus	Million Plus and Smart	50	
32		Solapur	Another city	Smart	25	
33	Madya Pradesh	Bhopal	Million Plus	Million Plus, Capital and Smart	100	340
34		Indore	Million Plus	Million Plus and Smart	100	
35		Gwalior	Million Plus	Million Plus and Smart	40	
36		Jabalpur	Million Plus	Million Plus and Smart	50	
37		Ujjain	Other City	Smart	50	
38	Odisha	Bhubaneshwar	Other City	Capital and Smart	50	50
39	Rajasthan	Jaipur	Million Plus	Million Plus, Capital and Smart	100	100
40	Telangana	Hyderabad	Four Million Plus	Million Plus and Capital	300	325
41		Warangal	Other City	Smart	25	
42	Tamil Nadu	Coimbatore	Million Plus	Million Plus and Smart	100	525
43		Tiruchirappalli	Million Plus	Million Plus and Smart	100	
44		Madurai	Million Plus	Million Plus and Smart	100	
45		Erode	Other City	Smart	50	
46		Tiruppur	Other City	Smart	50	
47		Salem	Other City	Smart	50	
48		Vellore	Other City	Smart	50	
49		Thanjavur	Other City	Smart	25	
50	Tripura	Agartala	Special Category	Capital and Smart	50	50
51	Uttarakhand	Dehradun	Special Category	Capital and Smart	30	30
52	Uttar Pradesh	Lucknow	Million Plus	Million Plus, Capital and Smart	100	600
53		Agra	Million Plus	Million Plus and Smart	100	
54		Kanpur	Million Plus	Million Plus and Smart	100	
55		Prayagraj	Million Plus	Million Plus and Smart	50	
56		Varanasi	Million Plus	Million Plus and Smart	50	
57		Ghaziabad	Million Plus	Million Plus and Satellite Town	50	
58		Meerut	Million Plus	Million Plus	50	
59		Bareilly	Other City	Smart	25	
60		Moradabad	Other City	Smart	25	
61		Aligarh	Other City	Smart	25	
62		Jhansi	Other City	Smart	25	
63	West Bengal	Haldiya	Other City	Million Plus, Satellite Town	50	100
64		Kolkata New Town	Other City	Smart	50	
Total					5,095	5,095
			Intercity operations			
Andhra Pradesh State Road Transport Corporation				Andhra Pradesh		50
Kadamba State Road Transport [STU, Govt.of Goa]				Goa		50
Gujarat State Road Transport Corporation				Gujarat		50
Karnataka State Road Transport Corporation				Karnataka		50
Maharashtra State Road Transport Corporation				Maharashtra		50
Rajasthan State Road Transport Corporation				Rajasthan		50

Uttarakhand Transport Corporation, Dehradun	Uttarakhand	50
Transport Department, Govt. of West Bengal	West Bengal	50
Total		**400**
Last Mile Connectivity		
Delhi Metro Rail Corporation	NCR Delhi	100
Total		**5,595**

Source: DHI

Appendix II: Summary of EV Policies in Various States in India

Sl No	State & Year of Release of EV Policy	Targets	Incentives
1	**Andhra Pradesh – 2018**	• 10 lakhs total EVs by 2024 • 100% electric buses by 2029 • 100% electric fleet in electric mobility cities by 2024	• Micro industries: 25% of fixed capital investment (FCI) – up to INR 15 lakhs • Medium industries: 20% of FCI – up to INR 40 lakhs • Large industries: 10% of FCI – up to 10 crores • Mega industries: 10% of FCI – up to 20 crores • Electricity duty: 100% – for 5 years • DC chargers(>=100V) 25% capital subsidy - 100 stations - INR 10 lakh • DC chargers(< 100V) 25% capital subsidy - first 300 stations - upto INR 30,000 • Swapping stations: 25% FCI - first 50 stations - upto INR 10 lakh • Stamp duty exemption, SGST Reimbursement, Electricity duty exemption, Road Tax Exemption, Registration Fee exemption – 100%
2	**Assam – 2021**	• BEVs to contribute 25% of all vehicle's registration by 2026 • 100% electric buses by 2030 • 100% of government vehicles to be converted to electric vehicles by 2030	• Manufacturing: Capital subsidy: (a) Micro units - 20% - upto INR 15 lakh; (b) Small units - 20% - upto INR 50 lakh; (c) Medium units - 20% - upto INR 1 Cr; (d) Large units - 10% - upto INR 10 Cr • 25% - first 500 PCS - INR 10 lakh • 2W - INR 10,000/ kWh; 3W - INR 10,000/ kWh; 4W - INR 10,000/ kWh • Road Tax Exemption, Registration Fee exemption – 100%
3	**Bihar - 2019**	• Total EV's - 100% by 2030 • 3W - 100% (manually paddled rickshaws) by 2022	• 2W - 15% - first 24,000 - upto INR 5,000 • 3W - 15% - first 70,000 - upto INR 12,000 • 4W - 15% (a) 4W BEV- first 4,000 - upto INR 1 lakh (b) 4W hybrid -first 1000 - upto INR 1 lakh • Buses - 15% - first 1000 - upto INR 20 lakh • Top up (BPL/SC/ST) subsidy : INR 8,000 ; Special incentive (Li-ion) of INR 10,000 • 25% - first 250 PCS - upto INR 10 lakh • Road Tax Exemption, Registration Fee exemption – 100%
4	**Chandigarh - 2022**	• Built Chandigarh as "Model EV City" • 100% EV (2W, 3W, 4W) by 2027	• Capital Subsidy: E-bicycle – Max INR 3,000; 2W – max INR 30,000; e-cart – max INR INR 30,000; e-autos – max INR 30,000; 4W – max INR 2,00,000 • PCS – Subsidy max INR 50,000 Only for first 50 fcharging /Swapping EVSE • Subsidy max INR 6,000 Only for first 30,000 private chargers

			• SGST Reimbursement, Electricity duty exemption – 100%
5	**Delhi - 2020**	• BEVs to contribute 25% of all vehicle's registration by 2024 • 1000 pure electric buses by 2020 • Delivery service providers to covert 100% of their fleet operators to electric by 2025	• 2W - Demand generation incentive: INR 30,000/ vehicle; Purchase incentive: INR 5,000/kWh - upto INR 30,0000 • 3W - Purchase incentive: INR 30,000/ vehicle; Interest subvention: 5% on loans • 4W - INR 10,000/kWh -first 1,000 - upto INR 1.5 lakh • Others - Goods carrier: INR 30,000 • Road Tax Exemption, Registration Fee exemption – 100%
6	**Goa - 2021**	• Total EV's - 30% (Annual vehicles registered) by 2025 • Ferries: 50% by 2025	• Capital Subsidy: (a) Pioneer, Mega & Large units - 20%; (b) Micro - 30% - upto INR 5 lakh; (c) Medium - 30% - upto INR 10 lakh; • Capital Subsidy EVCI: Electricity infrastructure cost: Upto INR 8 lakh; Solar powered charging station - 20% • 2W - INR 10,000/ kWh - upto INR 30,000/ vehicle • 3W - INR 10,000/ kWh - upto INR 30,000/ vehicle • 4W - INR 10,000/ kWh - upto INR 1,50,000/ vehicle • Stamp duty exemption, SGST Reimbursement, Road Tax Exemption – 100%
7	**Gujarat - 2021**	• 1,10,000 electric 2-wheelers by 2025 • 70,000 electric 3-wheelers by 2025 • 20,000 electric 4-wheelers by 2025	• 25% capital subsidy of the charging station equipment/machinery up to INR 10 lakhs for the first 250 commercial PCS • 2W - INR 10,000/kWh • 3W - INR 10,000/kWh • 4W - INR 10,000/kWh
8	**Haryana - 2022**	• Convert 100% of bus fleet into EV by 2029, with the first phase of 100% conversion of bus fleet in Gurugram and Faridabad by 2024. • Phase out all fossil fuel based commercial fleets and logistics vehicles in Gurugram and Faridabad by 2024 and all cities by 2030 • Government Vehicle – 100% EV by 2024	• Fixed capital subsidy: (a) Micro industries - 25% upto INR 15 lakhs (b) Small and medium industries - 20% upto INR 40 and 50 lakhs respectively (c) Large industries - 10% upto INR 10 crores (d) Mega industries - 10% upto INR 20 crores; Subsidy for sustainable green measures: 25% upto INR 50 crores • Capital Subsidy: • 2W - 30%; 3W - User subsidy: 30% ; Coupon: INR 25,000 • 4W - User subsidy: 30% ; Coupon: (a) Car < INR 10 lakhs - INR 75,000 (b) Car > INR 10 lakh - INR 1 lakh • Buses - 30% • Interest free loans (Government employees): 100% • 25% of fixed capital investment - first 50 PCS - upto INR 10 lakhs • DC chargers(>=100V) - 25% - first 100 stations - upto INR 10 lakhs • DC chargers(< 100V) - 25% - first 300 stations - upto INR 30,000

			• Stamp duty exemption, SGST Reimbursement, Electricity duty exemption, Road Tax Exemption – 100%
9	**Karnataka – 2017**	• Auto Rickshaws, Cab Aggregators, Corporate Fleets and School Buses/Vans to achieve 100% electric mobility by 2030 • 1000 electric buses by 2022 • EV 3-wheelers and 4-wheelers mini goods vehicles to achieve 100% electric mobility by 2030	• General Investment promotion subsidy: (a) Micro - 25% value of fixed assets (VFA) – up to INR 15 lakh (b) Small - 20% VFA – up to INR 40 lakh (c) Medium – up to INR 50 lakh; Investment subsidy (charging infra equipment/ BS infra): 20% VFA - first 5 units • DC chargers(>=100V) 25% - 100 stations - INR 10 lakh • Stamp duty exemption, SGST Reimbursement, Electricity duty exemption – 100%
10	**Kerala - 2019**	• 10,00,000 electric vehicles on road by 2022 • Pilot fleet of 200,000 2-wheelers, 50,000 3-wheelers, 1000 good carriers, 3000 buses and 100 ferry boats by 2020 • 100% electric buses by 2025	• DC chargers(>=100V) 25% - 100 stations - INR 10 lakh; DC chargers(< 100V) 25% - first 300 stations - upto INR 30,000; Capital subsidy: 25% of Fixed Capital Investment for BS stations - first 50 stations - upto INR 10 lakh • 3W - Incentive: INR 30,000 or 25% of EV • Road Tax Exemption, Registration Fee exemption – 100%
11	**Madhya Pradesh - 2019**	• 100% electric commercial and logistics fleet by 2028 • 100% electric buses by 2028 • 100% government vehicles by 2028	• PCS: Small: 25% capital subsidy of the charging equipment/machinery up to INR 1.5 lakhs for the first 300 stations; Medium: 25% capital subsidy of the charging equipment/machinery up to INR 2 lakhs for the first 100 stations; Large: 25% capital subsidy of the charging equipment/ machinery up to INR 10 lakhs for the first 100 stations • Motor Vehicle Tax Exemption limit: 99% for the first 15,000 electric 2-wheelers or total electric 2-wheelers in 5 years; 99% for the first 5,000 shared E-Rickshaws or total shared E-Rickshaws in 5 years; 99% for the first 5,000 electric auto-Rickshaws or total electric auto-Rickshaws in 5 years; 99% for the first 2,000 electric 3-wheeler goods carrier or total electric 3-wheeler goods carrier in 5 years; 99% for the first 6,000 electric cars or total electric cars in 5 years; 99% for the first 1,500 electric buses or total electric buses in 5 years • Registration Fee Exemption: 100% : (a) 2W - first 22,500 (b) 3W - first 7,500 (c) Rickshaw (shared and electric) - first 7,500 (d)Goods - first 3,000 (d) Car - first 9,000 (e) Buses - first 2,250
12	**Maharashtra - 2021**	• BEVs to contribute to 10% of new vehicle registrations by 2025 • 10% electric 2-wheelers by 2025 • 20% electric 3-wheelers by 2025 • 5% electric 4-wheelers by 2025	• 2W - INR 5,000/ kWh - first 1 lakh - upto INR 10,000 ; • 3W - INR 5,000/ kWh - first 15,000 - upto INR 30,000; • 4W -INR 5,000/ kWh - first 10,000 - upto INR 1.5L • Capital subsidy: (a)Slow - 60% - first 15,000 PCS - upto INR 10,000; (b) Moderate/ Fast - 50% - first 500 PCS - upto INR 5 lakh

		• 15% electric buses by 2025 (25% for Urban Agglomerations) • 25% electric fleet operators by 2025	• Road Tax Exemption, Registration Fee exemption – 100%
13	**Manipur – 2021**	• 15% electric vehicles by 2025	• 2W - INR 10,000/kWh up to INR 1.5 lakhs for the first 3,500 2W • 3W - INR 4,000/kWh up to INR 5 lakhs for the first 200 3W • 4W - INR 4,000/kWh up to INR 15 lakhs for the first 2500 electric 4-wheelers • INR 4,000/kWh up to INR 2 crores for the first 30 electric buses • Road Tax Exemption, Registration Fee exemption – 100%
14	**Meghalaya - 2021**	• Total EV's - 15% by 2025	• 2W - INR 10,000/ kWh - first 3,500 - upto INR 1.5 lakh • 3W - INR 4,000/kWh - first 200 - upto INR 5 lakh • 4W - (a) 4W: INR 4,000/ kWh - 2,500 - upto 15 lakh (b) Strong Hybrid 4W: INR 4,000/ kWh - first 30 - upto INR 15 lakh • Buses - INR 4,000/ kWh - first 30 - upto INR 2 crore • Road Tax Exemption, Registration Fee exemption – 100%
15	**Odisha - 2021**	• BEVs to contribute to 20% of total vehicle registrations by 2025	• Grant of INR 5000 for the first 20,000 private charging points; 25% capital subsidy to the selected energy operators for the first 500 charging stations • 2W - 15% up to INR 5000 • 3W - 15% up to INR 12,000 • 4W - 15% up to INR 1,00,000 • electric bus es: 10% up to INR 20 lakhs • Goods carriers: Purchase incentive of INR 30,000 for the first 5000 electric goods carriers • Micro and small enterprise: 25% of the capital investment made in plant and machinery up to INR 1 crore • Micro and small enterprise (owned by SC/ST/differently abled/women): 30% of the capital investment made in plant and machinery up to INR 1.25 crore • Micro and small enterprise (set up in industrially backWard districts): Additional 5% capital investment subsidy
16	**Punjab - 2019**	• Total EV's - 25% (New vehicles registered annually) by 2024 • 2W - 25% (New sales) by 2024 • 3W - 25% (New sales) by 2024 • 4W - Commercial fleet and delivery (New sales): 25% by 2024	• Capital Subsidy: 25% - first 1000 charging points - upto INR 50,000 • Stamp duty exemption, SGST Reimbursement, Motor Vehicle Exemption, Registration Fee exemption – 100%

		• Buses - 25% by 2024 • Government fleet: 100%	
17	**Rajasthan - 2021**	• Adoption of EV ecosystem in the state	• 2W: upto 2kWh – INR 5,000; upto 4kWh – INR 7,000; upto 5kWh – INR 9,000; more than 5kWh – INR 10,000 • 3W: upto 3kWh – INR 10,000; upto 4kWh – INR 15,000; upto 5kWh – INR 17,000; more than 5kWh – INR 20,000 • SGST Reimbursement & Registration Fee exemption – 100%
18	**Tamil Nadu - 2019**	• To attract INR50,000 crore (INR500 billion) of investment in EV manufacturing and create a comprehensive EV ecosystem in the State; create 1.5 lakh new jobs	• Capital subsidy: 15% - over 10 years for investments till, Battery manufacturing subsidy: (a) 20% - 20 years (b) Southern districts: 50% - 20 years ; Additional capital subsidy (MSME-EV component): 20% over existing capital subsidy • Stamp duty exemption, SGST Reimbursement, Electricity duty exemption, Road Tax Exemption, Registration Fee exemption – 100%
19	**Telangana – 2020**	• To make Telangana a major base for EV & ESS sectors and to attract investments worth $ 4.0 Billion and create employment for 120,000 persons by year 2030 through EVs in shared mobility, charging infrastructure development and EV & ESS manufacturing activities	• Capital investment subsidy: 20% of investment up to INR 30 crore • Power Tariff Discount: 25% for 5 years capped at 5 Cr. for Mega Enterprises; Electricity Duty Exemption: 100% for 5 years capped at 0.5 Cr • Stamp duty exemption, SGST Reimbursement, Road Tax Exemption, Registration Fee exemption – 100%
20	**Uttar Pradesh – 2019**	• 10 lakhs EVs by 2024 • 1000 electric buses by 2030 • Goods: 100% by 2030	• Technology transfer for alternate clean fuel mobility: Anchor EBUs: 100% cost - 5 vendor units & 75% cost - next 5 vendor units -up to INR 50 lakh; Ultra mega battery plant: 50% cost -up to INR 10 lakh • 25% capital subsidy on fixed capital investment up to 6 lakhs for the first 100 PCS • Stamp duty exemption, SGST Reimbursement, Electricity duty exemption, Registration Fee exemption – 100% • Road Tax Exemption:100% for electric 2-wheelers; 75% for other electric vehicles
21	**Uttarakhand – 2018**	• 500 electric buses by 2023	• Electricity duty exemption, Motor Vehicle Tax Exemption – 100% • SGST reimbursement: MSME and large - 30% - for 5 years; Investment above INR 50 crore - 50% - for 5 years
22	**West Bengal – 2021**	• 10 lakhs EVs by 2026 • Public and semi-public charging stations: 1 lakh by 2026 • EV to public charging point ratio - 8:1	

Source: State EV policies

Appendix III: Key Requirements for Selection of EV Charging Equipment[16]

Key Requirements	Description
Environmental requirements	The operational range of the EVSE in environmental conditions such as temperature, humidity, pressure, storage temperature etc. The environmental requirements stated in per AIS 138 Part I: • Ambient temperature range: 0°C to 55°C • Ambient humidity: 5% to 95% as per AIS 138 Part I • Ambient pressure: 86 kpa to 106 kpa as per AIS 138 Part I section 11.11.2.4 • Storage temperature: 0°C to 60°C
Mechanical requirements	The mechanical requirements of an EVSE tests the system for mechanical impact, ingress protection, mechanical stability and cooling function. Some of the standards/values accepted while procurement of a DC 001 charger: • Ingress protection: The minimum IP degrees for ingress of objects is IP 54 • Mechanical Impact: As per IEC 61851 -1 Section 11 .11 .2 • Mechanical Stability: As per section 11 .11 .2.2. of AIS 138 Part • Cooling: Air cooled or forced cool for protection and safety of equipment from any fire hazards
Protection requirements	The protection requirements ensures the EVSE is equipped to sustain an electric shock, and provide protection for over current, under voltage, over voltage, residual current, surge protection, short circuit, earth fault at input and output, input phase reversal, over temperature and emergency shut-down with alarm. AIS 138 Part I specifies the standard for protection against electric shock and earthing: • Protection against electric shock – Section 7.0 • Effective earth continuity between the enclosure and the external protective circuit - Section 6.4.1.2 • Cable – As per AIS 138 Part ½; length of cord will be 5 meter; cord extension as per Section 6.3.1 of AIS 138 Part I
Specific requirements	Specific requirements related to EVSE includes output power, charging current, load dump etc. These requirements are in accordance with IEC 61851 standard: • Rated outputs and maximum output power: IEC 61851 - 23 (Section 101.2.1.1) • Descending rate of charging current: IEC 61851-23 (Section 1 01.2.1.4) • Load dump: IEC61851-23 (Annex BB 3.8.3)

---

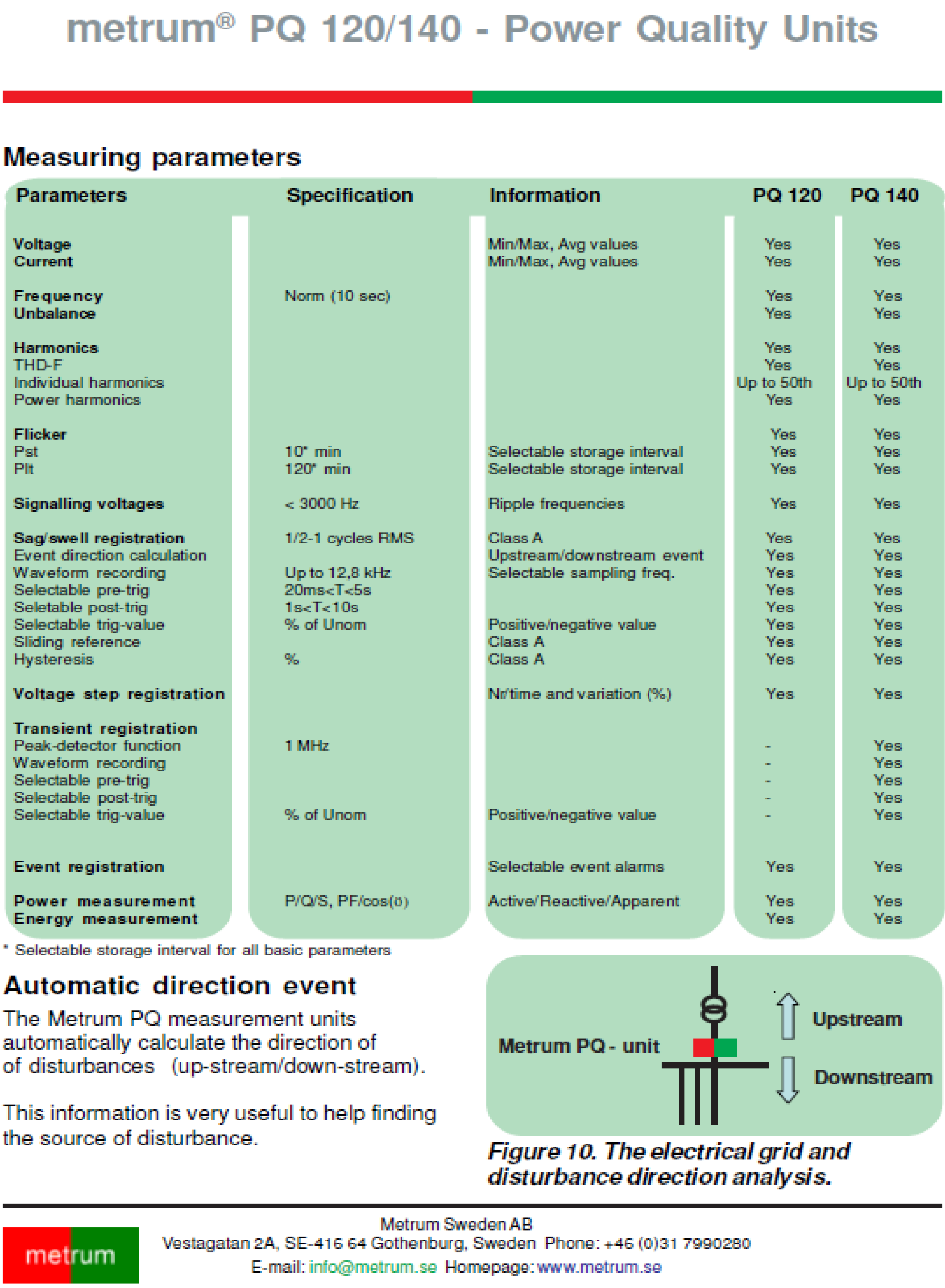
[16] Report - Status quo analysis of various segments of electric mobility and low carbon passenger road transport in India by GIZ

Functional requirements	The functional requirements of EVSE equipment deals with its current and voltage levels. The guidance for the same is provided in AIS 138-2 standard. • Measuring current and voltage: AIS 138-2 • Voltage measurement: ± 0,5% • Current measurement: ±1 A if the actual current is less than or equal to 50 A
Communication requirements	Appropriate communication system in an EVSE system is highly essential. The EVSE should have feature to remotely connect with a Central Management System (CMS) which will have the authorization to approve or modify any activity in the EVSE. • Communication between EV and EV charging station should be through a physical layer of Controller Area Network (CAN) bus. CAN bus should comply with the requirement of ISO 11898 -2: 2003 • AIS 138-2 provides details about the system definition for communication between DC EV charging station and electric vehicle • For EVSE to CMS communication, the general requirement is through Ethernet/Wi-Fi/2G/3G/4G technologies. Also, the CMS system must use Open Charge Point Protocol (OCPP) • CMS must have the authorization for allowing/disallowing charging of an electric vehicle • Reliable Internet connectivity is another requirement of the EVSE system • Metering is another requirement of EVSE. A grid responsive metering as per units consumption of the vehicle must be in place with the EVSE. The central system should be able to access the metering information from any remote location.
Billing and payment requirements	For billing and payments in the charging station: • Billing should be done through a grid responsive meter which is in line with Indian metering standard • Payments should be compliant with authorized mobile payment platforms (BHIM, Bharat QR, UPI etc.)
Performance requirements	The performance requirements of EVSE can assessed on the basis of output voltage and current. The approved value of the performance parameters is defined in AIS 138 standards. Below are some of such requirements: **DC output and current tolerance requirements**: • DC output current regulation in Constant Current Charging (CCC): ± 2.5 A for the requirement below 50 A, and ± 5 % of the required value for 50 A or more • DC output voltage regulation in Constant Voltage Charging (CVC): Max. 2 % for the max rated voltage of the EVSE **Control delay of charging current in CCC requirements:** • DC output current demand response time: <1 s ramp up rate: 20 A/s or more and ramp down rate: 100 A/s or more **DC output current ripple limit of EVSE:** • 1.5 A below 10 Hz,

	• 6 A below 5 kHz, • 9A below 150 kHz **Periodic and random deviation (Voltage ripple)** • Max. ripple voltage: ± 5 V • Max slew rate: ± 20 V/ms
User interface and display requirements	The user interface and display of an EVSE system should have: • ON/OFF (Start-Stop) switches • Emergency stop switch • Visual indicators • Display • Support language • Display messages • User authentication and end of charging
Marking and painting requirements	Guidelines for markings on the EVSE is provided in AIS 138 standard. Some of the mandated markings given in AIS 138 standard are: • Name or initials of manufacturer • Equipment reference • Serial number • Date of manufacture; rated voltage in V; rated frequency in Hz; rated Current in A; number of phases • IP degrees

Appendix IV: Datasheet of Power Quality Meter

Technical Specification of Power Quality Meter (PQ 140) Installed in Pune



metrum® PQ 120/140 - Power Quality Units

Measuring parameters

Parameters	Specification	Information	PQ 120	PQ 140
Voltage		Min/Max, Avg values	Yes	Yes
Current		Min/Max, Avg values	Yes	Yes
Frequency	Norm (10 sec)		Yes	Yes
Unbalance			Yes	Yes
Harmonics			Yes	Yes
THD-F			Yes	Yes
Individual harmonics			Up to 50th	Up to 50th
Power harmonics			Yes	Yes
Flicker			Yes	Yes
Pst	10* min	Selectable storage interval	Yes	Yes
Plt	120* min	Selectable storage interval	Yes	Yes
Signalling voltages	< 3000 Hz	Ripple frequencies	Yes	Yes
Sag/swell registration	1/2-1 cycles RMS	Class A	Yes	Yes
Event direction calculation		Upstream/downstream event	Yes	Yes
Waveform recording	Up to 12,8 kHz	Selectable sampling freq.	Yes	Yes
Selectable pre-trig	20ms<T<5s		Yes	Yes
Seletable post-trig	1s<T<10s		Yes	Yes
Selectable trig-value	% of Unom	Positive/negative value	Yes	Yes
Sliding reference		Class A	Yes	Yes
Hysteresis	%	Class A	Yes	Yes
Voltage step registration		Nr/time and variation (%)	Yes	Yes
Transient registration				
Peak-detector function	1 MHz		-	Yes
Waveform recording			-	Yes
Selectable pre-trig			-	Yes
Selectable post-trig			-	Yes
Selectable trig-value	% of Unom	Positive/negative value	-	Yes
Event registration		Selectable event alarms	Yes	Yes
Power measurement	P/Q/S, PF/cos(φ)	Active/Reactive/Apparent	Yes	Yes
Energy measurement			Yes	Yes

* Selectable storage interval for all basic parameters

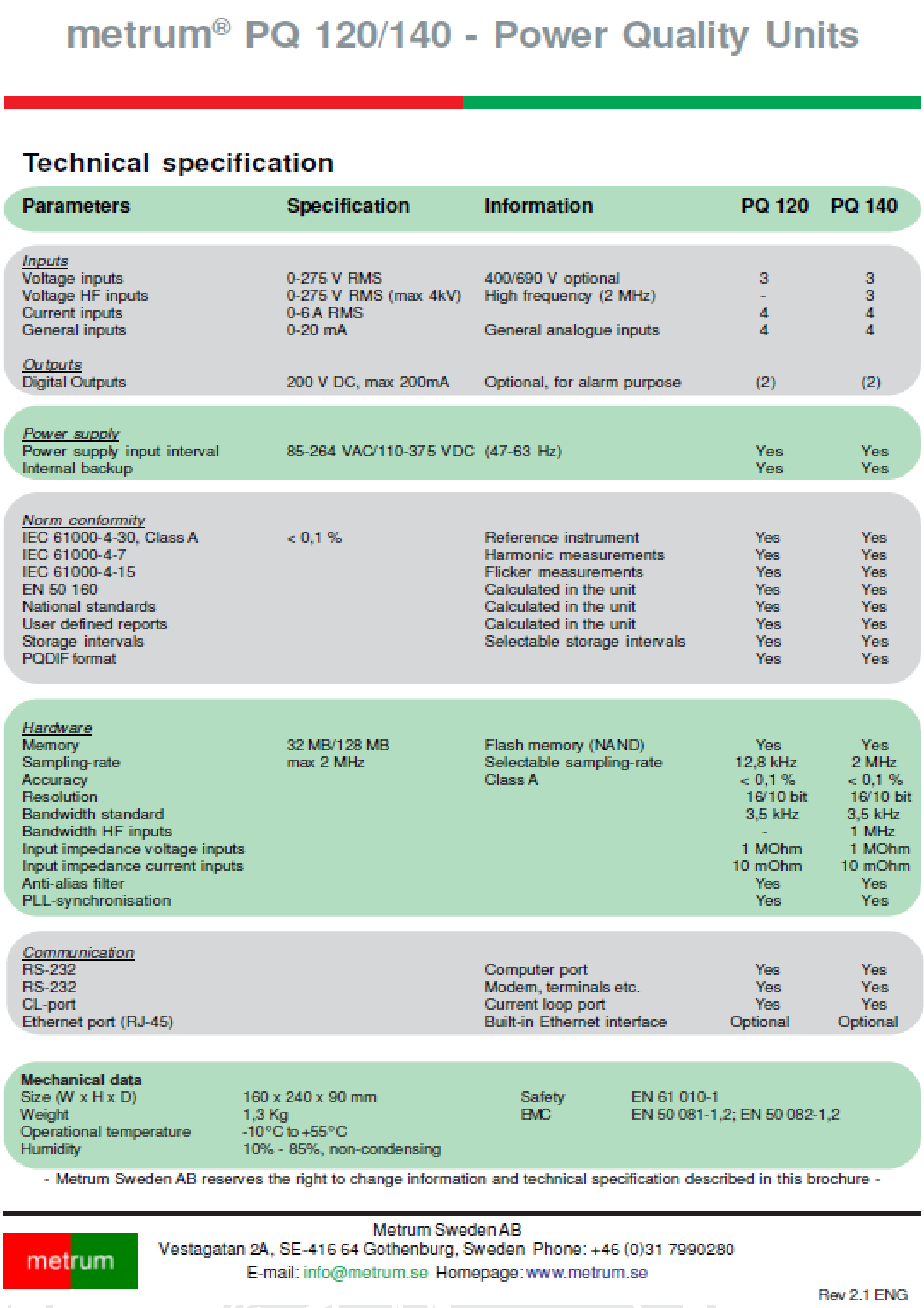
Automatic direction event

The Metrum PQ measurement units automatically calculate the direction of of disturbances (up-stream/down-stream).

This information is very useful to help finding the source of disturbance.

Figure 10. The electrical grid and disturbance direction analysis.

metrum
Metrum Sweden AB
Vestagatan 2A, SE-416 64 Gothenburg, Sweden Phone: +46 (0)31 7990280
E-mail: info@metrum.se Homepage: www.metrum.se



metrum® PQ 120/140 - Power Quality Units

Technical specification

Parameters	Specification	Information	PQ 120	PQ 140
Inputs				
Voltage inputs	0-275 V RMS	400/690 V optional	3	3
Voltage HF inputs	0-275 V RMS (max 4kV)	High frequency (2 MHz)	-	3
Current inputs	0-6 A RMS		4	4
General inputs	0-20 mA	General analogue inputs	4	4
Outputs				
Digital Outputs	200 V DC, max 200mA	Optional, for alarm purpose	(2)	(2)
Power supply				
Power supply input interval	85-264 VAC/110-375 VDC	(47-63 Hz)	Yes	Yes
Internal backup			Yes	Yes
Norm conformity				
IEC 61000-4-30, Class A	< 0,1 %	Reference instrument	Yes	Yes
IEC 61000-4-7		Harmonic measurements	Yes	Yes
IEC 61000-4-15		Flicker measurements	Yes	Yes
EN 50 160		Calculated in the unit	Yes	Yes
National standards		Calculated in the unit	Yes	Yes
User defined reports		Calculated in the unit	Yes	Yes
Storage intervals		Selectable storage intervals	Yes	Yes
PQDIF format			Yes	Yes
Hardware				
Memory	32 MB/128 MB	Flash memory (NAND)	Yes	Yes
Sampling-rate	max 2 MHz	Selectable sampling-rate	12,8 kHz	2 MHz
Accuracy		Class A	< 0,1 %	< 0,1 %
Resolution			16/10 bit	16/10 bit
Bandwidth standard			3,5 kHz	3,5 kHz
Bandwidth HF inputs			-	1 MHz
Input impedance voltage inputs			1 MOhm	1 MOhm
Input impedance current inputs			10 mOhm	10 mOhm
Anti-alias filter			Yes	Yes
PLL-synchronisation			Yes	Yes
Communication				
RS-232		Computer port	Yes	Yes
RS-232		Modem, terminals etc.	Yes	Yes
CL-port		Current loop port	Yes	Yes
Ethernet port (RJ-45)		Built-in Ethernet interface	Optional	Optional

Mechanical data			
Size (W x H x D)	160 x 240 x 90 mm	Safety	EN 61 010-1
Weight	1,3 Kg	EMC	EN 50 081-1,2; EN 50 082-1,2
Operational temperature	-10°C to +55°C		
Humidity	10% - 85%, non-condensing		

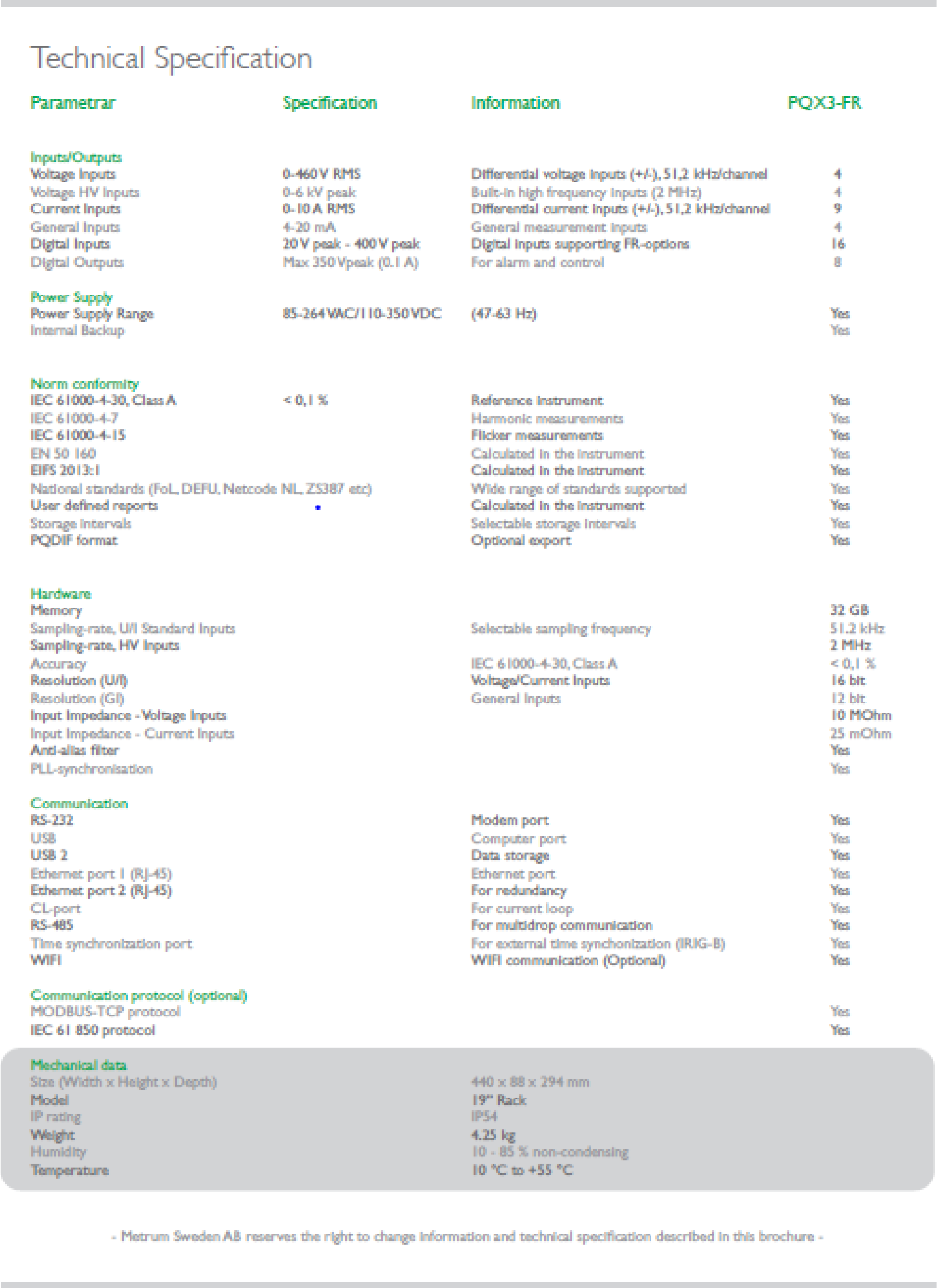
- Metrum Sweden AB reserves the right to change information and technical specification described in this brochure -

metrum

Metrum Sweden AB
Vestagatan 2A, SE-416 64 Gothenburg, Sweden Phone: +46 (0)31 7990280
E-mail: info@metrum.se Homepage: www.metrum.se

Rev 2.1 ENG

Technical Specification of Power Quality Meter Installed (PQX3-FR) in Kolkata



Technical Specification

Parametrar	Specification	Information	PQX3-FR
Inputs/Outputs			
Voltage Inputs	0-460 V RMS	Differential voltage inputs (+/-), 51,2 kHz/channel	4
Voltage HV Inputs	0-6 kV peak	Built-in high frequency inputs (2 MHz)	4
Current Inputs	0-10 A RMS	Differential current inputs (+/-), 51,2 kHz/channel	9
General Inputs	4-20 mA	General measurement inputs	4
Digital Inputs	20 V peak - 400 V peak	Digital inputs supporting FR-options	16
Digital Outputs	Max 350 Vpeak (0.1 A)	For alarm and control	8
Power Supply			
Power Supply Range	85-264 VAC/110-350 VDC	(47-63 Hz)	Yes
Internal Backup			Yes
Norm conformity			
IEC 61000-4-30, Class A	< 0,1 %	Reference instrument	Yes
IEC 61000-4-7		Harmonic measurements	Yes
IEC 61000-4-15		Flicker measurements	Yes
EN 50 160		Calculated in the instrument	Yes
EIFS 2013:1		Calculated in the instrument	Yes
National standards (FoL, DEFU, Netcode NL, ZS387 etc)		Wide range of standards supported	Yes
User defined reports		Calculated in the instrument	Yes
Storage intervals		Selectable storage intervals	Yes
PQDIF format		Optional export	Yes
Hardware			
Memory			32 GB
Sampling-rate, U/I Standard Inputs		Selectable sampling frequency	51.2 kHz
Sampling-rate, HV Inputs			2 MHz
Accuracy		IEC 61000-4-30, Class A	< 0,1 %
Resolution (U/I)		Voltage/Current Inputs	16 bit
Resolution (GI)		General Inputs	12 bit
Input Impedance - Voltage Inputs			10 MOhm
Input Impedance - Current Inputs			25 mOhm
Anti-alias filter			Yes
PLL-synchronisation			Yes
Communication			
RS-232		Modem port	Yes
USB		Computer port	Yes
USB 2		Data storage	Yes
Ethernet port 1 (RJ-45)		Ethernet port	Yes
Ethernet port 2 (RJ-45)		For redundancy	Yes
CL-port		For current loop	Yes
RS-485		For multidrop communication	Yes
Time synchronization port		For external time synchonization (IRIG-B)	Yes
WIFI		WIFI communication (Optional)	Yes
Communication protocol (optional)			
MODBUS-TCP protocol			Yes
IEC 61 850 protocol			Yes
Mechanical data			
Size (Width x Height x Depth)		440 x 88 x 294 mm	
Model		19" Rack	
IP rating		IP54	
Weight		4.25 kg	
Humidity		10 - 85 % non-condensing	
Temperature		10 °C to +55 °C	

- Metrum Sweden AB reserves the right to change information and technical specification described in this brochure -

Appendix V: Transients Recorded at EV Charging Station at Pune

Sl No	Date	Time	Duration(sec)	Voltage (Volt)
1	06-09-2021	07:25:43	0.004766	-7094.00
2	16-09-2021	08:53:52	0.0004688	6244.00
3	14-10-2021	09:04:08	0.0002344	-18740.00
4	16-10-2021	07:56:24	0.0002344	17690.00
5	16-10-2021	08:52:54	0.000781	17690.00
6	01-12-2021	07:43:42	0.0005469	13670.00
7	02-12-2021	06:25:12	0.001641	8248.00
8	03-12-2021	02:20:51	0.0001563	1974.00
9	28-12-2021	07:06:43	0.0003906	-15640.00
10	29-12-2021	06:54:52	0.0003906	-10770.00
11	31-12-2021	07:20:59	0.0003125	-15730.00
12	01-01-2022	07:33:58	0.0002344	13800.00
13	02-01-2022	07:32:40	0.0003125	-15140.00
14	03-01-2022	07:06:31	0.0003906	16250.00
15	04-01-2022	06:53:33	0.0003125	-13980.00
16	05-01-2022	07:11:10	0.0003125	15430.00
17	06-01-2022	07:16:25	0.0003906	14820.00
18	13-01-2022	07:53:44	0.0003906	-16230.00
19	14-01-2022	07:39:29	0.0003125	-14710.00
20	15-01-2022	07:33:32	0.0003125	16100.00
21	16-01-2022	07:49:53	0.0003906	-16020.00
22	24-01-2022	07:10:58	0.0003906	-15460.00
23	25-01-2022	07:19:37	0.0003906	15810.00
24	26-01-2022	08:35:00	0.001328	-5311.00
25	27-01-2022	07:18:47	0.0001563	-17590.00
26	04-02-2022	07:28:06	0.0003125	-13970.00
27	05-02-2022	07:15:01	0.0003906	14360.00
28	09-02-2022	06:02:12	0.0003906	-1492.00
29	09-02-2022	11:01:30	7.813E-05	0.00
30	09-02-2022	11:03:15	0.0003125	-11660.00
31	10-02-2022	06:18:03	0.0003125	12150.00
32	11-02-2022	07:11:08	0.0003125	13350.00
33	26-02-2022	07:10:38	0.0002344	-13640.00
34	27-02-2022	08:53:35	0.0003125	-15110.00
35	28-02-2022	07:08:40	0.0002344	-14240.00
36	01-03-2022	09:24:24	0.0002344	13230.00
37	02-03-2022	05:59:25	0.0025	11030.00

38	02-03-2022	08:47:53	0.0003125	15800.00
39	02-03-2022	02:18:39	0.0004688	18150.00
40	02-03-2022	06:25:54	0.00007813	18150.00
41	03-03-2022	09:33:36	0.0003125	15650.00
42	04-03-2022	08:59:50	0.0003125	15580.00
43	05-03-2022	07:22:25	0.0003125	15300.00
44	06-03-2022	09:59:47	0.0003125	-15740.00
45	07-03-2022	07:12:49	0.0002344	-11570.00
46	08-03-2022	09:52:48	0.0003906	-14970.00
47	09-03-2022	09:02:43	0.0003125	14820.00
48	10-03-2022	09:35:36	0.0010940	19030.00
49	11-03-2022	10:00:39	0.0003906	-13970.00
50	11-03-2022	07:50:29	0.0021090	13430.00
51	11-03-2022	11:05:36	0.0036720	-5030.00
52	12-03-2022	01:40:04	0.0003125	11130.00
53	12-03-2022	07:36:12	0.0003906	-12800.00
54	12-03-2022	12:50:31	0.0003906	18550.00
55	14-03-2022	08:38:54	0.0003906	-14340.00
56	15-03-2022	08:47:29	0.0003125	-11960.00
57	15-03-2022	01:07:15	0.0001563	15620.00
58	16-03-2022	09:00:36	0.0003125	-13310.00
59	17-03-2022	09:00:12	0.0003906	13610.00
60	17-03-2022	10:31:40	0.0002344	-7885.00
61	18-03-2022	11:00:47	0.0003906	-14780.00
62	19-03-2022	08:53:21	0.0003906	-14540.00
63	20-03-2022	09:56:09	0.0003125	13850.00
64	20-03-2022	03:04:57	0.0005469	12450.00
65	21-03-2022	08:35:21	0.0003125	12580.00
66	22-03-2022	09:36:11	0.0004688	15080.00
67	23-03-2022	01:52:32	0.0040630	12830.00
68	23-03-2022	08:39:59	0.0003906	14950.00
69	24-03-2022	10:53:16	0.0002344	-17950.00
70	25-03-2022	09:50:16	0.0002344	-13690.00
71	26-03-2022	09:32:43	0.0003125	11950.00
72	26-03-2022	10:16:47	0.0010160	-3403.00
73	27-03-2022	08:19:38	0.0001563	19710.00
74	28-03-2022	08:34:22	0.0003906	-14590.00
75	28-03-2022	03:28:18	0.0003125	11510.00
76	29-03-2022	10:13:47	0.0003125	14760.00
77	30-03-2022	09:42:37	0.0003125	-13320.00
78	31-03-2022	10:16:32	0.0002344	-13670.00
79	09-04-2022	09:47:02	0.0003125	12600.00
80	10-04-2022	11:01:22	0.0003906	14220.00
81	11-04-2022	08:44:28	0.0003906	-14370.00

82	12-04-2022	08:49:03	0.0004688	13470.00
83	13-04-2022	08:02:01	0.0014060	-6410.00
84	13-04-2022	08:40:02	0.0003125	13000.00
85	14-04-2022	08:30:21	0.0003906	12790.00
86	15-04-2022	08:56:53	0.0002344	9266.00
87	16-04-2022	10:36:56	0.0003125	-12640.00
88	17-04-2022	11:38:51	0.0003906	-15680.00
89	18-04-2022	09:08:21	0.0003906	-15220.00
90	19-04-2022	09:09:05	0.0003906	-14870.00
91	20-04-2022	08:59:27	0.0003125	-12760.00
92	22-04-2022	10:00:23	0.0004688	15330.00
93	22-04-2022	08:46:53	0.0001563	-11550.00
94	22-04-2022	09:45:49	0.00007813	-11550.00
95	23-04-2022	09:05:38	0.0003906	-12320.00
96	24-04-2022	11:08:15	0.0003906	-14900.00
97	25-04-2022	08:37:39	0.0001563	14350.00
98	26-04-2022	08:52:16	0.0003906	14500.00
99	27-04-2022	09:05:04	0.0003906	-15020.00
100	27-04-2022	10:00:43	0.0003906	14090.00
101	28-04-2022	09:55:27	0.0003906	-13720.00
102	28-04-2022	10:45:31	0.0004688	-14060.00
103	29-04-2022	08:43:23	0.0004688	13600.00
104	30-04-2022	05:03:55	0.0046880	10150.00
105	30-04-2022	10:08:24	0.0003125	13090.00
106	02-05-2022	08:37:12	0.0004688	-13290.00
107	18-05-2022	09:03:12	0.0003906	-15550.00
108	19-05-2022	02:30:16	0.0002344	17690.00
109	19-05-2022	08:22:59	0.0001563	15100.00
110	19-05-2022	09:57:59	0.0003906	-15370.00
111	20-05-2022	02:58:10	0.0003125	-15380.00
112	21-05-2022	07:47:14	0.0005469	-3875.00
113	21-05-2022	09:40:41	0.0002344	13130.00
114	21-05-2022	02:42:33	0.0003906	14810.00
115	23-05-2022	08:52:45	0.0003906	-15520.00
116	23-05-2022	02:43:07	0.0003906	6651.00
117	24-05-2022	08:58:56	0.0001563	8256.00
118	25-05-2022	08:31:42	0.0003906	14300.00
119	25-05-2022	02:25:38	0.0003906	13780.00
120	26-05-2022	09:02:54	0.0003906	14380.00
121	27-05-2022	09:02:46	0.0022660	10050.00
122	27-05-2022	09:47:06	0.0004688	14310.00
123	28-05-2022	11:08:11	0.0003906	-14740.00
124	30-05-2022	02:18:39	0.0003906	-15210.00
125	30-05-2022	03:24:49	0.00007813	-15210.00

126	30-05-2022	04:10:59	0.0021880	9133.00
127	30-05-2022	08:29:41	0.0003906	10600.00
128	31-05-2022	08:31:44	0.0003906	15680.00
129	02-06-2022	09:01:27	0.0003906	15680.00
130	03-06-2022	08:06:03	0.0028910	-4031.00
131	03-06-2022	09:22:49	0.0003125	-14990.00
132	09-06-2022	10:51:02	0.00007813	0.00
133	10-06-2022	09:14:24	0.0003906	15810.00
134	11-06-2022	10:10:51	0.0003906	15830.00
135	12-06-2022	12:38:19	0.0010940	-17420.00
136	12-06-2022	01:35:06	0.0013280	-16700.00
137	13-06-2022	08:55:55	0.0003906	-14630.00
138	13-06-2022	02:44:58	0.0021880	-13430.00
139	14-06-2022	08:55:43	0.0003906	14570.00
140	15-06-2022	08:25:43	0.0003906	14990.00
141	17-06-2022	07:47:31	0.00007813	14990.00
142	17-06-2022	06:43:04	0.0024220	1786.00
143	18-06-2022	07:19:58	0.00007813	1786.00
144	20-06-2022	07:49:17	0.00007813	0.00
145	21-06-2022	07:54:27	0.0003906	-14530.00
146	22-06-2022	07:32:20	0.0004688	-14700.00
147	23-06-2022	05:30:42	0.0003906	-6159.00
148	23-06-2022	08:48:45	0.0003125	-4136.00
149	23-06-2022	05:41:58	0.0008594	-16450.00
150	24-06-2022	01:47:16	0.0019530	-914.90
151	25-06-2022	08:57:55	0.0002344	-12110.00
152	25-06-2022	11:18:57	0.0002344	-19660.00
153	26-06-2022	02:50:49	0.00007813	-19660.00
154	26-06-2022	07:40:11	0.0003125	18540.00
155	26-06-2022	11:14:41	0.0021880	17010.00
156	28-06-2022	08:59:43	0.0003906	-14380.00
157	28-06-2022	07:25:24	0.0049220	15700.00
158	29-06-2022	08:44:08	0.0003906	-15300.00
159	30-06-2022	07:12:51	0.0003906	13850.00
160	01-07-2022	08:55:13	0.0002344	-11440.00
161	01-07-2022	09:57:05	0.0003906	5047.00
162	02-07-2022	09:26:41	0.0002344	10580.00
163	04-07-2022	08:44:29	0.0003906	-15230.00
164	05-07-2022	09:12:24	0.0003125	-13700.00
165	06-07-2022	09:04:22	0.0001563	11840.00
166	07-07-2022	09:31:45	0.0003906	-15570.00
167	07-07-2022	11:22:04	0.0035160	12390.00
168	07-07-2022	12:27:01	0.0028910	17330.00
169	08-07-2022	07:21:45	0.0002344	-18230.00

170	09-07-2022	08:54:07	0.0003125	15810.00
171	09-07-2022	10:40:07	0.0031250	-14840.00
172	09-07-2022	11:27:31	0.0006250	2650.00
173	09-07-2022	02:57:08	0.0015630	1651.00
174	09-07-2022	04:51:40	0.0002344	-8246.00
175	10-07-2022	09:54:09	0.0003906	-12380.00
176	11-07-2022	07:38:54	0.0003125	7353.00
177	12-07-2022	08:59:54	0.0003906	-11730.00
178	13-07-2022	08:57:20	0.0013280	-16200.00
179	13-07-2022	09:02:56	0.0003125	13370.00
180	14-07-2022	01:51:27	0.0028910	-1982.00
181	14-07-2022	07:55:16	0.0014060	-9870.00
182	14-07-2022	07:58:24	0.0028910	-25090.00

Appendix VI: Key Parameters, Standards for EVSE[17]

Parameters	Standard	Specified Limit and Actions Required
Protection	CEA (Technical standards for connectivity of the distributed generation resources) Regulations, 2013, as amended from time to time.	Detection of various faults/abnormal conditions and provision of appropriate means to isolate the faulty equipment or system automatically. Ensure that fault of charging equipment or charging system does not affect grid adversely.
Harmonic Current	IEEE 519 – 2014 CEA (Technical standards for connectivity of the distributed generation resources) Regulations, 2013, as amended from time to time.	Harmonic current injections from the generating system do not exceed the limit specified in IEEE 519.
DC Injection	IEEE 519 – 2014 CEA (Technical standards for connectivity of the distributed generation resources) Regulations, 2013, as amended from time to time.	Prosumer shall not inject direct current greater than 0.5% of rated output at the interconnection point.
Voltage Sag, Voltage Swell, Flicker, Disruptions, etc.	Relevant BIS standards or as per IEC/IEEE standards if BIS not available.	Power quality parameters.
Overload	CEA (Measures relating to safety and electric supply) Regulations, 2010, as amended from time to time.	All EV charging stations shall be provided with protection against the overload of input supply and output supply fittings.
Installation Height	CEA (Measures relating to safety and electric supply) Regulations, 2010, as amended from time to time.	All EV charging stations shall be installed so that any socket-outlet of supply is at least 800 mm above the finished ground level.
Cord extension set or second cable assembly	CEA (Measures relating to safety and electric supply) Regulations, 2010, as amended from time to time.	A cord extension set, or second cable assembly shall not be used in addition to the cable assembly for the connection of the EV to the EV charging point. A cable assembly shall be so constructed so that it cannot be used as a cord extension set.

---

[17] Source: Report by GIZ on **Status quo analysis of various segments of electric mobility and low carbon passenger road transport in India, 2022**

Adaptors	CEA (Measures relating to safety and electric supply) Regulations, 2010, as amended from time to time.	Adaptors shall not be used to connect a vehicle connector to a vehicle inlet.
Maximum Cable Length/ Parking Space	CEA (Measures relating to safety and electric supply) Regulations, 2010, as amended from time to time.	Maximum length of the supply lead is 5m/parking Place shall be within five meter from the electric vehicle charging point.
Portable socket-outlets	CEA (Measures relating to safety and electric supply) Regulations, 2010, as amended from time to time.	Portable socket-outlets are not permitted to be used for EV charging.
Lightning Protection	CEA (Measures relating to safety and electric supply) Regulations. IS/IEC 62305	Suitable lightning protection system shall be provided for the EVs charging stations as per IS/IEC 62305.
Protective Device	CEA (Measures relating to safety and electric supply) Regulations	The EVs charging stations shall be equipped with a protective device against the uncontrolled reverse power flow from vehicle.
Disconnection of EV from the Supply	CEA (Measures relating to safety and electric supply) Regulations. IEC 60950	• One second after having disconnected the EV from the supply (mains), the voltage between accessible conductive parts or any accessible conductive part and earth shall be less than or equal to 42.4 V peak (30 V_{rms}), or 60 V DC, and the stored energy available shall be less than 20 J (as per IEC 60950) • A warning label shall be attached in an appropriate position on the charging stations in case voltage is greater than 42.4 V peak (30 V_{rms}), or 60 V DC or the stored energy is 20 J or more
Locking of the Coupler	CEA (Measures relating to safety and electric supply) Regulations	• A vehicle connector used for DC charging shall be locked on a vehicle inlet if the voltage is higher than 60 V DC • The vehicle connector shall not be unlocked (if the locking mechanism is engaged) when hazardous voltage is detected through charging process including after the end of charging • In case of charging system malfunction, a means for safe disconnection may be provided
Protection against overvoltage at the battery	CEA (Measures relating to safety and electric supply) Regulations.	The DC EV charging point shall disconnect supply of electricity to prevent overvoltage at the battery, if output voltage exceeds maximum voltage limit sent by the vehicle.

Verification of Vehicle Connector Voltage	CEA (Measures relating to safety and electric supply) Regulations.	The EV charging station shall not energize the charging cable when the vehicle connector is unlocked. The voltage at which the vehicle connector unlocks shall be lower than 60 V.
Residual Current Devices (RCDs)	CEA (Measures relating to safety and electric supply) Regulations.	All Residual Current Device (RCDs) for the protection of supplies for EVs: • Shall have a residual operating current of not greater than 30 mA • Shall operate to interrupt all live conductors, including the neutral • Shall have a performance at least equal to Type A and be in conformity with IS 732-2018 • These shall be permanently marked to identify their function and the location of the charging station or socket outlet they protect • Where required for service reasons, discrimination (selectivity) shall be maintained between the residual current device protecting a connecting point and a residual current device installed upstream • The owner of the charging station shall ensure that the tests as specified in the manufacturer's instructions for the residual current device and the charging station have been carried out
Overcurrent Protection Device	CEA (Measures relating to safety and electric supply) Regulations.	• Each EV charging station shall be supplied individually by a dedicated final sub-circuit protected by an overcurrent protective device complying with IEC 60947-2, IEC 60947-6-2 or the IEC 60269 series • The overcurrent protective device shall be part of a switchboard • Coordination of various protective device shall be required
Voltage Independent RCD	CEA (Measures relating to safety and electric supply) Regulations.	All EV charging stations shall be supplied from a Sub-circuit protected by a voltage independent RCD and also providing personal protection that is compatible with a charging supply for an EV.
Earth Continuity Monitoring System	CEA (Measures relating to safety and electric supply) Regulations.	All EV charging stations shall be provided with an earth continuity monitoring system that disconnects the supply in the event that the earthing connection to the vehicle becomes ineffective.
Earthing	IS – 732	Earthing of all EV charging stations shall be TN system as per IS 732.

Cable	CEA (Measures relating to safety and electric supply) Regulations.	• The cable may be fitted with an earth connected metal shielding. The cable insulation shall be wear resistant and maintain flexibility over the full temperature range. • Power supply cables used in charging station or charging points shall conform to IEC 62893-1 and its relevant parts
Detection of the electrical continuity by the protective conductor	CEA (Measures relating to safety and electric supply) Regulations	• A protective earth conductor shall be provided to establish an equipotential connection between the earth terminal of the supply and the conductive parts of the vehicle • The protective conductor shall be of sufficient rating to satisfy the requirements of IEC 60364-5-54
Firefighting System	CEA (Measures relating to safety and electric supply) Regulations.	Firefighting system for EVs charging stations shall be as per relevant provisions of CEA (Measures relating to safety and electric supply) regulations 2010.
Enclosure	CEA (Measures relating to safety and electric supply) Regulations.	Enclosure of charging stations shall be made of fire retardant material with self-extinguishing property and free from halogen.
Alarm and Control System	CEA (Measures relating to safety and electric supply) Regulations.	Fire detection, alarm and control system shall be provided as per relevant IS.
Insulation Resistance	IEC: 61851 – 1	All apparatus of EV charging station shall have the insulation resistance value as stipulated in the relevant IEC 61851-1.
Energisation of Charging Stations	CEA (Measures relating to safety and electric supply) Regulations.	Every charging station shall be tested and inspected by the electrical inspector or chartered electrical safety engineer before energisation of charging stations.
Periodical Maintenance	CEA (Measures relating to safety and electric supply) Regulations.	• An electric vehicle charging station operator shall arrange periodic test/inspection of an EV charging station or EVSE should be carried out by electrical inspector/CESE in every year in the initial period of first three years after the energisation of charging station and in every four years thereafter. • The owner/operator shall establish and implement a safety assessment programme for regularly assessing the electrical safety of EVSE, conductors and fittings.
Ingress Protection	IEC 60529	Where the connection point is installed outdoors, or in a damp location, the equipment shall have a degree of protection of at least IPX4 in accordance with IEC 60529.

Maintenance of Records	CEA (Measures relating to safety and electric supply) Regulations.	• The owner of the charging station shall keep records in regard to design, construction and labelling to be compatible with a supply of standard voltage at a nominal frequency of 50 Hz of the charging station. • The owner of the charging station shall keep records of the relevant test certificate as indicated in these regulations and as per IEC 61851. • The owner of the charging station shall keep records of the results of every inspection, testing and periodic assessment and details of any issues observed during the assessment and any actions required to be taken in relation to those issues. • The owner of the charging station shall retain a copy of all records, as specified in sub regulation.
International Standards for Charging Stations	CEA (Measures relating to safety and electric supply) Regulations.	• The safety provisions of all AC charging stations shall be in accordance with IEC 61851-1, IEC 61851-21 and IEC 61851-22. • The safety provisions of all DC charging stations shall be in accordance with IEC 61851-1, IEC 61851-21, IEC 61851-23 and IEC 61851-24.

Appendix VII: Standard Operating Procedures for EVSE in Bus Depots

Standards Operating Procedures for EVSE in Bus Depots

As already mentioned, thousands of bus depots require MW-scale electricity connections to support charging of electric bus fleet. In order to install high-capacity chargers and ensure its safe operation and maintenance, it is important to have a set of standard operating procedures (SOP) which need to be followed by all relevant stakeholders – electric utilities, transport companies, municipal corporations, fleet operators, electric bus OEMs and EVSE OEMs. A draft guideline for the SOP for EVSE in bus depot is given in below sections.

Installation of EVSE in Bus Depots

The following procedures need to be followed for installation of EVSEs at bus depots[18]:

- The location selected for installation of EVSE in the bus depot should not be prone to flooding by rain water or other means
- Obtain electricity connection in the bus depot from the electric utility in sufficient capacity for the planned electric bus deployment for next 10 years
- The new distribution transformer (DT) and cables may be sized to take care of the power requirement for electric bus chargers in next 10 years
- Make sure that there is enough space around the chargers to carry out secure operation and maintenance work at the bus depots
- Proper distance to be maintained between the charging units so that buses can be parked safely
- Ensure the materials used and the installation procedures follow the local building codes and safety standards
- The EVSE should be installed only by a qualified engineer who is trained and certified for EVSE installation
- Ensure the cable slack is sufficient to guide the cables in the cabinet
- Ensure water cannot enter the charging unit cabinet
- Ensure the earthing connection is in accordance with the standard IEC 60364-5-54
- Ensure internet access through 2G/3G/4G/5G or through a wired ethernet connection
- Make sure the electric wire and ethernet cable conduit is aligned with the EVSE input wire opening prior to installation - failure to do so could damage the wiring or the charger

---

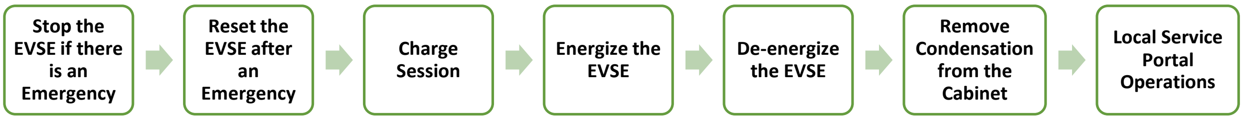
[18] These norms may be adopted for installation of EVSE in all public charging stations (PCS) also

- Establish and maintain any appropriate measures (such as installation of firewalls, application of authentication measures, encryption of data, installation of anti-virus programs, etc); and protect the product, the network, its system and the interface against any kind of security breaches, unauthorized access, interference, intrusion, leakage and/or theft of data or information
- Before commissioning the EVSEs, DISCOM engineer must inspect and certify
- If the EVSE load is more than 50 kW, a power quality meter (PQM) should be installed and the readings of which should be monitored by both electric bus operators and electric utility engineer
- If the EVSE load is more than 200 kW, the installation must be inspected and approved by the Electrical Inspectorate of the state

Operation and Management of Charging Stations

In order to ensure proper utilization of the charging infrastructure and the electric buses in a bus depot, it is essential to standardize the on-site management and create a good working environment. Some of the key points are mentioned below.

- During the charging process, the vehicle is prohibited from driving, and can only be charged when it is stationary - make sure that the vehicle is parked at the designated spot before charging session starts
- Ensure the connector of the charger cable can conveniently reach the connection port of the electric bus
- Insert the charging gun into the bus to ensure the reliable connection between the gun and the bus - the connection light is on
- In wet weather, make sure that the charging gun head and the electric vehicle socket are dry – if it is wet, charging is prohibited
- It is advised to unplug the charging gun once the charging session is finished
- Special fire-fighting equipment should be equipped near the charging pile for emergencies
- If the charging equipment is found to be leaking during the charging process of the electric bus, the charging should be stopped immediately, and the professional maintenance personnel should be contacted for maintenance
- Five to ten minutes of cooling off period may be allowed between two charging sessions



- Prepare an emergency plan that instructs operators what to do in case of an emergency
- Obtain approval of a trained technician/engineer from the manufacturer or a third party to use the EVSE after commissioning
- Ensure the space around the EVSE cannot get blocked by any objects
- If the EVSE is de-energized for more than two hours, activate the internal heater to remove condensation from the cabinet
- Chargers need to be regularly repaired and maintained as per OEMs manuals
- Keep strict on-site discipline and hygiene

- Fire safety and other safety precautions should be followed in the charging station area
- All employees deployed in the charging station area should be familiar with the location of fire-fighting equipment and how to use them, and be familiar with safety communication protocols
- Unauthorized entry and movement of personnel in the charging area should be banned
- Charging station operators must concentrate when operating the charging equipment
- On-site personnel shall not do things unrelated to the work during the work period; and conduct inspections from time to time
- Charging station operators should be familiar with the performance characteristics of the EVSEs
- Need to check the charging equipment regularly to reduce failures and accidents
- If the charging equipment is found to be abnormal, a fault tag must be attached to it immediately; and report the matter to the maintenance team
- Smoking, spitting and littering are strictly prohibited in the charging station area
- Raw garbage must be cleaned up and disposed of in the designated areas regularly

Charging Station Safety Rules and Regulations

- Establish a mechanism for accountability to individuals
- Report to the supervisor in a timely manner and take effective measures when discovering potential safety hazards
- New employees are strictly prohibited from working alone during the probationary period
- In the event of lightning and thunder, must suspend the charging operations and turn off the power to all the EVSEs
- Check the operation status of the EVSEs once in a day
- Organise weekly, monthly and quarterly inspections at charging station and keep the records for future reference
- The voluntary fire brigade shall regularly organize and conduct implement fire training activities
- Consistently educate workers in safety procedures and regulations to improve and consolidate employee safety awareness and capabilities
- Establish employee training sessions for electrical safety skills ideally once a month or at least quarterly

Maintenance of EVSE at Bus Depots

- **Charge Gun:** When charger gun is not in use, try to avoid direct exposure of the gun head to the outside, and plug it back into the socket to prevent damages. If the charging gun head has problems such as damaged casing or exposed cable, do not use it; and report the matter to the maintenance team
- Extreme care should be taken to avoid dropping of charging gun while handling, this may lead to damage to the critical component
- **Charging Function:** Communicate with the charger operator or driver to see if there is abnormal charging
- **Backend Connection:** Check to ensure that the EVSE is connected to the server
- **Power Record:** Download the data once in a month as follow-up operation data analysis
- **Screw Inspection:** Check whether all the screws are properly fastened, especially those on the high current side

- **Power Module:** Check regularly whether the power and current output capacities are normal

The table below presents recommended maintenance schedule of the EVSEs in the bus depots[19].

Table 0-1: Maintenance Schedule of EVSEs at Bus Depots

Sl No	Description	Inspection Frequency		
		30 Days	60 Days	90 Days
1	**Cleaning**			
	Removal of dust from external surfaces of charger (using cloth)	X		
	Removal of dust from internal surfaces (by air jet or vacuum cleaner)	X		
	Cleaning of charger air filters	X		
	Cleaning of charger output cables outer surface	X		
	Air jet blowing in charger's gun connectors	X		
	Charger cabinet door easily locked or not	X		
2	**Moulded Case Circuit Breaker (MCCB)**			
	Tightness of MCCB input and output connections			X
	Continuity between MCCB input and output terminals			X
	Condition of all MCCBs			X
	MCCB manual tripping			X
3	**Wirings (Specific)**			
	Condition of wiring and ferrule marking			X
	Flexibility of wiring			X
	Continuity of wiring, to check abnormalities			X
4	**Protection Devices**			
	Condition/status of MCBs			X
	Condition/status of surge protection device			X
	Condition/status of earth leakage relay			X
	Condition/status of overvoltage/undervoltage protection relay			X
	Condition/status of HVDC fuses			X
5	**Sensors/Alarms**			
	Emergency alarm			X
	Cabinet temperature sensor alarm			X
	Mains power supply sensor alarm			X
	Other system fault alarm			X
6	**LEDs**			
	Mains power indication LED			X
	Connector charging status indication LED			X
	System fault indication LED			X
	Charger indoor LEDs working status			X
7	**Communication**			
	Cloud connectivity check	X		
	GSM indication signal	X		
8	**Foundation**			
	Tightness of nuts and bolts			X
	If necessary, replace nuts and bolts			X
9	**Earthing or Grounding**			
	Grounding resistance < 5 Ohm		X	
	Equipment grounding		X	
	System grounding		X	
10	**Electrical Parameters - Input (AC)**			

---

[19] These are general recommendations; each OEM may be prescribing maintenance schedule for their equipment which may be followed.

	Phase to phase voltage and current on full load		X	
	Phase to neutral voltage and current on full load		X	
	Neutral to ground voltage and current on full load		X	
	Phase to phase voltage and current on no load		X	
	Phase to neutral voltage and current on no load		X	
	Neutral to ground voltage and current on no Load		X	
11	**Electrical parameters- output (DC)**			
	Charger output voltage		X	
	Charger output current		X	

Emergency Plans at Bus Depots

Emergency Plan for EVSE

The steps to deal with dangerous situations such as smoke and fire in the charging box and control box are:

- Break the emergency stop switch
- Evacuation of people and vehicles
- Cut off the power supply of the distribution box
- Put out the fire using the fire extinguishers for electrical fires

Emergency Plan for Electric Bus

- Effectively prevent and handle safety emergencies in the charging process of electric buses
- Minimize its harm and impact in accordance with relevant national laws and regulations

Emergency Plan in case of Fire in Charging Station

- When a fire accident occurs, all parties should deal with it in a timely and orderly manner with the sole motto of "**saving people is more important than fighting fire**”
- Take measures to control fire from spreading; and then eliminate it
- Take the injured people (if any) to medical help
- When a fire occurs, the finder immediately calls for help, sends out a fire signal, and immediately turns off the power supply
- Evacuate the station area, stop all operations, and prohibit other vehicles and unwanted personnel from entering the station area
- If feasible and risk not involved, remove the vehicles adjacent to fire
- The firefighters immediately use the firefighting equipment in the station area to put out the fire
- After the fire is extinguished, carefully check whether there is any dark fire on the scene, prevent the fire from recurring, and clean up the area
- Count the damaged materials, and make detailed records and archives
- After the fire is extinguished, summarize and analyse the reasons, make rectification and report immediately
- Carry out education and training on safety among all employees to prevent the recurrence of similar incidents

Emergency Plan for Major Vehicle Accidents

- Organize and carry out accident handling work to avoid accident escalation and protect people's lives and property

DO’s and DON’Ts

Some of the important DO’s and DON’T’s are summarized below.

DO’s

- Ensure that the charging connector is docked at all times when not in use
- Make sure the upstream breaker (MCCB or ELCB) for the AC power supply is OFF, when EVSEs are not in operation
- Ensure the charging cable is free from any physical damages
- Ensure the charging cable is securely wound around the saddle when the charger is not in use
- Use a damp cloth or sponge to clean the panels
- Turn “OFF” power at the panel board or load centre before working inside the equipment or removing any component
- Disconnect electrical power to the DC charger before any maintenance work to ensure it is separated from the supply of AC mains - failure to do so may cause physical injury or damage to the electrical system and charging unit
- Identify the hazards (in terms of a risk assessment) resulting from the working conditions on the site
- Park and lock the bus properly and engage handbrake before connecting the charging gun to the bus
- At the time of charging if any issue occurs in the bus, press charger emergency button to stop the charging
- After charging complete, kindly roll the cable and keep gun into the holder back
- Charge the bus in a well-ventilated area to avoid suffocation from toxic flames in case of fire
- If any smoky smell coming from the socket/charger, then stop/switch off the current
- Unplug and disconnect the charger if it heats up excessively
- Regularly check the charging cable for cuts/damages

DON’Ts

- Don’t forget to wear insulating rubber gloves and electrically resistive shoes during maintenance of the EVSE
- Don’t put tools, material, or body parts into the electric bus connector
- Don’t use the charger if the chassis, power cord or charging cable are frayed, have broken insulation, or any other signs of damages
- Don’t install or use the charger if the enclosure is broken, cracked, open or has any other indications of damage
- Don’t leave the back door of the EVSE open, exposing live parts
- Don’t leave the charging connector on the ground
- Don’t jerk or twist the charging cable
- Don’t perform any installation or maintenance work on the charger, unless the mains connection to the charger has been disconnected
- Don’t wash the charger with forced water
- Don’t perform live-wire operations

- Don’t remove circuit protective devices or any other component until the power is turned “OFF”.
- Don’t touch the variable resistors on the controller printed circuit board
- Don’t touch the inside of the EVSE while it is in operation
- Don’t forget to return the protective cover to its original state after inspections
- Don’t try to pull cable to connect into the vehicle if vehicle is parked far from charge point
- Don’t try to open the charger and don’t touch the charger with wet hands
- Don’t smoke at charging stations

India Smart Grid Forum

India Smart Grid Forum
CBIP Building, Malcha Marg, Chanakyapuri
New Delhi 110021
Tel: 091-11-41030398
Email: contactus@indiasmartgrid.org
www.indiasmartgrid.org