UNIVERSITY of RWANDA COLLEGE OF SCIENCE AND TECHNOLOGY ACE-ESD AFRICAN CENTER OF EXCELLENCE IN ENER SUSTAINABLE DEVEL

Dissertation Title:

Feasibility Study of Electric Vehicle Integration in Rwandan Distribution Network

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African Centre of Excellence in Energy for Sustainable Development (ACE-ESD)

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DECLARATION

I declare that this Dissertation contains my own work except where specifically acknowledged, and it has been passed through anti-plagiarism system and found to be compliant and this the approved final version of the thesis.

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ABSTRACT

Electric vehicles integration in the distribution network are expected to increase the base and peak electric loads on the power system, increases technical losses, increases harmonic distortion and reduces the stability of the power system. Meanwhile, when used with bidirectional inverters as battery chargers, electric vehicles can work in V2G mode as EES and strengthen grid stability. This dissertation discusses how electric vehicles impacts voltage stability, power loss, harmonic distortion and system loading. In addition, the study proposes a design of electrical power supply for battery charging referring to the battery specifications available to the local markets. The model of battery chargers is developed in MATLAB software while distribution network test is conducted on a 34 buses taken from KINIGI feeder of CampBelge substation in northern corridor of nation grid by using ETAP software. The test came up with locating electric vehicles charging stations by taking into account the aforementioned factors, where 4, 1,2,2 and1 vehicles are located at 19, 20,23,25 and 26 respectively.

Key words: Voltage stability, Electric vehicle, harmonic distortion, distribution network and charging equipment.

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ACRONYMS

AC: Alternating Current

CO2: Carbon Dioxide

Cu: Copper

DC: Direct Current

ETAP: Electrical Transient and Analysis Program

EVs: Electric Vehicles

EVSE: Electric Vehicle Supply Equipment

Fnom: Nominal Frequency

GHG: Green House Gases

HEV: Hybrid Electric Vehicle

IC: Internal Combustion

IGBT: Insulated Gate Bipolar Transistor

MoE: Ministry of Environment

PHEV: Plug-in Hybrid Electric Vehicle

Prated: Rated Power

PWM: Pulse Width Modulation

REMA: Rwanda Environment Management Authority

RHSs: Reactive Harmonic suppressors

RMS: Root Mean Square

RURA: Rwanda Utility Regulatory Agency

SCs: Switching Harmonic Suppressors

tCO2e: Tonnes of carbon dioxide equivalent

THD: Total Harmonic Distortion

Vnom: Nominal Voltage

VSF: Voltage Stability Factor

VSI: Voltage Sensibility Index

1. INTRODUCTION

Transport in Rwanda is mainly based on road transport and the energy sector in Rwanda classifies it among the top ten contributors of GHG emissions since it is currently based on diesel powered cars. In order to mitigate the greenhouse gasses emission, fossil-fuel resources scarcity and fuel dependency, various alternatives such as the use of electric vehicles (EVs) and fuel efficiency technologies were proposed by MoE in its Third National Communication Report to the United Nations Framework Convention on Climate Change suggested. On the other hand, the EVs require electrical energy to be powered which in turns should be fossil fuel dependent and hence contribute to the GHG emissions. Therefore, the mitigation solutions should be applied to the electrical power generation by using renewable energy resources.

In this thesis, an emphasize is made on plug-in-electric vehicles though the distribution network and its analysis were performed to find its readiness to cope with an increased load during charging period and still providing accurate service reliability.

1.1 BACKGROUND

The issues like exhausting fossil fuel reserves, GHG emissions and global warming require direct attention to ensure future sustainability. Since the transport sector is among the most significant contributors to the growing detrimental emissions, electrification of transport facilities is viewed as a viable answer to this issue. There is more than a century since existence of Electric vehicle (EV) technology climaxing commercially around 1900. However, due to the abundance of fossil fuels, IC technology advancements, and straightforward application of IC engines, EVs were put on hold and limited to golf carts and delivery vehicles. Figure 1 shows the progression timeline of the EVs worldwide[1].

However, the uptake of electric vehicles (EVs) is still gradual as a result of variables like high capital costs, battery decline, inadequate infrastructure for charging among others. Several policies and inducements are made available by governments around the world to encourage the uptake of EV and to keep these obstacles at bay from grasping a complete shift to electrified transportation.

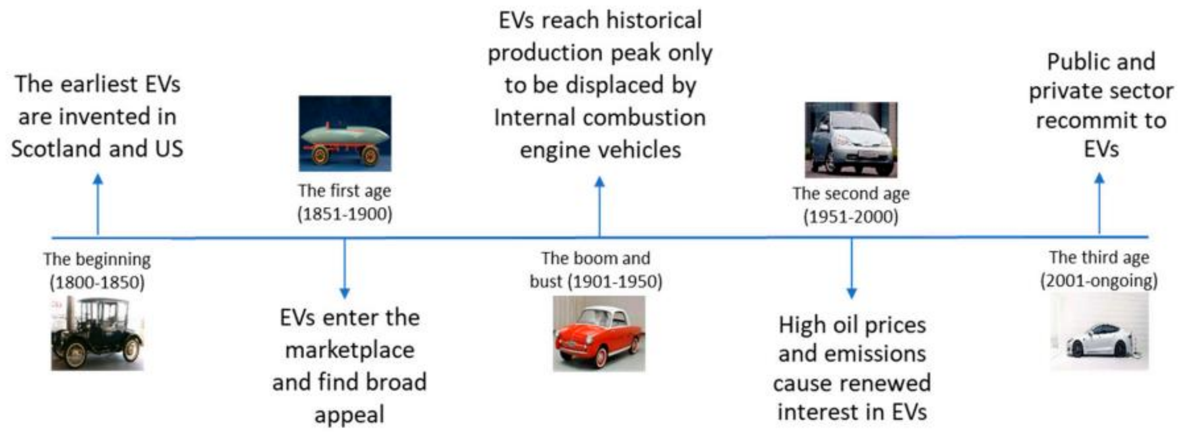


Figure 1.1The evolution of electric vehicles (EVs)

The high penetration of EVs leads to power system problems especially distribution quality issues, voltage imbalances in three phases, network congestion and off-nominal frequency problems. EVs are mobile single-phase loads randomly plugged in at any one of three phase lines within distribution networks, leading to a scenario that electrical components in one particular phase, such as power supply cable, overhead line or transformer may be heavily loaded while the rest of two phases are not. The unbalanced three-phase loading may lead to a series of negative impacts on power quality issues such as transformer failures, equipment loss of life, relay malfunction, etc. Moreover, as EVs are highly spatial and temporally uncertain, it is not an easy job to handle EVs as additional loads while maintaining the system reliability and security.

The EV home charging and residential load peaks time coincidence lead to additional system peaks. Moreover, the power quality is gradually reduced due to harmonics produced by rising number of chargers on the distribution line.

As articulated in Vision 2050, Rwanda committed to be a carbon free nation by the end of this vision and aims to reduce GHG emissions by 38% (an estimated mitigation of 4.6 million tCO2e) compared to business as usual by 2030 and Electric vehicles are thought to account for 9% of all possible energy-related emissions mitigated under the country's ten years climate action plan. It is against this background that the **Rwanda Environment Management Authority (**REMA) took carriage of its first electric vehicle to be used for the purpose of supporting the institution's mandate of environmental protection and has urged governmental and private institutions, as well as people, to consider switching to electric vehicles and participating in the fight against air pollution. [2][3][4][5].

To be able to charge the EVs batteries the charging stations should be installed countrywide near the roads, bus stations and bus terminals. This should make existing distribution network heavily loaded and reduce the service reliability which can even led to service cut if care does not have been taken.

1.2 PROBLEM STATEMENT

Rwanda as a developing country is still struggling in providing sufficient infrastructures including power system to meet the growing load demand. The peak load demand forecasted in 2020 is 174MW and 187MW in 2025 at 10% growth. On the other side the increasing level of EVs penetration in the distribution network tend to increase the load demand, as well as the peak demand leading to increased voltage drop, system imbalance, power loss stability and reliability problems as well. The location of charging station and the recommended time for charging should be an issue depending on the distribution network capacity and loadability. In this thesis the status (voltage and load profiles) of distribution network is assessed to find out the number of charging stations and the charging schedule arrangement to be availed in order to accommodate the increased load due to plug-in electric vehicles and/or to forecast the implementation of electric vehicles integration.

1.3 RESEARCH OBJECTIVES

1.3.1 MAJOR OBJECTIVES

The main objective of this thesis is to determine whether Rwandan power system is ready for accommodating electric vehicles as mean of transport in order to respond to problems derived from fuel based transport facilities**.**

1.3.2 THE SPECIFIC OBJECTIVE

The specific objectives of this thesis are:

1. To determine appropriate charging hours for electric vehicles
2. To propose the suitable location of charging stations
3. To design electric power supply of electric vehicle charging system

1.4 SCOPE OF THE STUDY

This study is limited to plug-in electric vehicles being charged from utility grid through well-placed electric chargers. The study is conducted on a 34 bus line from Campbelge substation where the load profiles are assessed and distribution network ability to integrate EV is studied.

1.5 EXPECTED OUTCOMES AND SIGNIFICANCE OF THE STUDY

1.5.1 EXPECTED OUTCOME OF THE STUDY

The expected outcome of this study is a proposed implementation schedule of electric vehicle in Rwandan distribution network by considering existing power system infrastructure, load demand and power quality issues.

1.5.2 SIGNIFICANT OF THE STUDY

The significance of this study is to address the issues which should arise if the implementation of EV integration is not well matched with the power system status and conditions as a result the policy makers and investors should invest more in energy sector to build up emission free transport facilities thus reducing environmental harms connected to fuel based vehicles.

2. LITERATURE REVIEW

Electric vehicles rely too much on distribution system reliability as the latter is more client load point oriented instead of being system oriented, and the local distribution system is considered rather than the whole integrated system involving the generation and transmission facilities. The distribution system reliability refers to the analysis of system failures, causes and consequences or it is the probability that the system will perform its intended function under specified working conditions for a specific period of time.

2.1 TYPES OF ELECTRIC VEHICLES

EVs are classified into three broad categories such as Battery Electric Vehicle (BEV), Plugin Hybrid Electric Vehicle (PHEV) and Hybrid Electric Vehicle (HEV) described in more details below.

2.1.1 BATTERY ELECTRIC VEHICLE (BEV)

It is driven by a d.c electric motor supplied from battery and plugged into the grid to recharge its battery. The drive of BEV works independently from the traditional internal combustion engine and its battery is allowed to be recharged through a regenerative braking to recover some of the energy wasted during braking.

2.1.2 PLUG-IN HYBRID ELECTRIC VEHICLE (PHEV)

In contrast to BEV, PHEV is driven by electric motor supplied from a battery but requires a support of an IC engine to charge the battery and /or to drive the system when the battery is about to die which results in fuel cost savings when compared with IC engine drive alone.

2.1.3 HYBRID ELECTRIC VEHICLE (HEV)

HEVs operate in complementary of gasoline engine with fuel tank and an electric motor with a battery drive system. The transmission can be turned simultaneously by both the electric motor and the engine which in turn turns the wheels. HEVs cannot be recharged from utility instead all the energy to be used, comes from gasoline and from regenerative braking.

2.1.4 BATTERY OF ELECTRIC VEHICLES

In the last years, battery development sees great advancements. In addition, an increment of 66% production of EVs batteries has reached worldwide which is unquestionably linked to an increase in the number of vehicle sales, with the forecast predicting the demand of batteries keeps growing. In fact, the latest predictions show that the supply and the demand of EVs will be even gradually rising in the coming years. The main characteristics of batteries include capacity, charge state, specific energy, specific power, charge cycle, lifespan internal resistance and efficacy.

The table below shows electric vehicle battery with corresponding manufacturer[6].

Table 2.1 Battery capacities of different electric vehicles

Vehicle	Year	Capacity (kWh)
Audi duo	1983	8
Volkswagen Jetta	1985	17.3
citySTROMer	1987	8
Volkswagen Golf	1988	10
Škoda Favorit	1990	9
Fiat Panda Elettra	1996	16.5
General Motors EV1	1997	10
Audi duo	1999	18.7
General Motors EV1	2000	26.4
General Motors EV1	2006	53
Tesla Roadster	2007	13.2
Smart ed	2007	53
Tesla Roadster	2009	72
BYD e6	2009	16
Mitsubishi i-MiEV	2009	24
Nissan Leaf	2009	16.5
Smart ed	2009	53
Tesla Roadster	2010	48
BYD e6	2010	60
Mercedes-Benz SLS	2010	26.5
AMG E-Drive	2010	53
Tata Indica Vista EV	2010	24
Tesla Roadster	2010	11.3
Volvo C30 EV	2011	32
Volvo V70 PHEV	2011	16
BMW ActiveE	2011	60

BMW i3	2011	23
BYD e6	2011	8, 12
Ford Focus Electric	2011	10.5
Mia electric	2011	22
Mitsubishi i-MiEV	2012	21.3
Renault Fluence Z.E	2012	23
Chevrolet Spark EV	2012	22
Ford Focus Electric	2012	40, 60, 85
Renault Zoe	2013	22
Tesla Model S	2013	64
BMW i3	2013	17.6
BYD e6	2013	26.5
Smart ed	2014	22
Volkswagen e-Golf	2014	80
Renault Fluence Z.E	2015	19
Tesla Roadster	2015	28
Chevrolet Spark EV	2015	70, 90
Mercedes Clase B ED	2016	82
Tesla Model S	2016	18.4
BYD e6	2016	27
Chevrolet Volt	2016	30
Kia Soul EV	2016	41
Nissan Leaf	2016	50, 75
Renault Zoe	2016	90, 100
Tesla Model 3	2017	33
Tesla Model X	2017	33.5
BMW i3	2017	25.5
Ford Focus Electric	2017	90
Honda Clarity EV	2017	40
Jaguar I-Pace	2017	75, 100
Nissan Leaf	2017	35.8

Tesla Model S	2018	95
Volkswagen e-Golf	2018	30
Audi e-tron	2018	60
Kia Soul EV	2018	60
Nissan Leaf	2018	100
Renault ZOE 2	2018	70, 90
Renault ZOE 2 rs	2019	70
Tesla Model 3	2019	60
Mercedes-Benz EQ	2019	100
Nissan Leaf	2020	95
Volvo 40 series	2020	42
Audi e-tron	2020	64
BMW i3	2020	93
Hyundai Kona e	2020	32.6
Mercedes EQC	2020	50
Mini Cooper SE	2021	77
Peugeot e-208	2021	99
Volkswagen ID.3	2022	200
Ford Mustang Mach-E		
Tesla Roaster		

2.2 CHARGING BASICS

Electric vehicle batteries charging increases the load demand. The size and variance of this increase depends on the EV uptake levels, the power rating of the EV chargers, and the connection period of these vehicles to the electricity supply system [7].

The charging stations connected to the grid belongs to grid the power loads, resulting in power load redistribution, causing the trend of change and net loss increases, as shown nonconforming charging means charging users according to their needs and charge habit, anytime, anywhere to the electric vehicle charging. The non-coordinated charging conditions, the electric automobile will have a significant peak power load connected to the grid at night, resulting in increased power load and voltage deviation increases, the grid network losses increase, as a result the grid's transmission efficiency is weak, and the condition of the grid is deteriorating [7].

The rate at which an electric vehicle's battery is charged, is used to classify charging equipment for electric vehicles. The factors upon which the charging times vary such as the battery's electric capacity, type (Lithium-ion, lead-acid, etc.), the battery depletion ratio, the type EVSE used and the electricity supply.

AC Level 1 Charging, AC Level 2 Charging and DC Level 2 Charging, also known as 'DC Fast Charging' are the main types of EVSE. The first two, as their names suggest, employ alternating current, whereas the third uses a direct current flow. The table below summarizes their most crucial characteristics [8].

Table 2.2 Charging equipment

Type of supply	**Level**	**Voltage Input (Volts)**	**Charging Rate (miles of range per 1 hour of charging)**
AC	1	120V AC	3.2-8 km/charging hr
	2	240V AC	16-32 km/charging hr
DC	2	480V AC three-phase	80-113 km in 20 minutes

The AC Level 1 EVSE charges the battery through a 120V AC plug via a power cord. Most of the plug-in vehicles currently in the market come with an AC Level 1 charging cord set and therefore the owner does not need to purchase any additional charging equipment. This charging method has the slowest charging rate, as it can be seen in Table 2.2, and so it is typically used when there are only 120V outlets available. With this type of charging equipment one can easily charge their plug-in vehicle from home. The AC Level 2 charging equipment utilizes a 240V electrical supply, offering a higher charging rate than the AC Level 1 does and thus reduces the vehicle's charging time considerably.

2.3 IMPACT OF ELECTRIC VEHICLE CHARGING IN POWER SYSTEM

As it is shown in the previous paragraphs, electric vehicle battery capacities do not allow to be used for a long time and also due to long period of charging depending on the type of technology, enormous charging stations have to be installed and spaced at least by 50km or less to enable recharging of batteries. Therefore, it increases the load growth on the power system which in turn should lead to poor system reliability and services interruptions. To cope with this issue a well scheduled charging time and number of station should be set in line with generation, transmission and distribution system capabilities.

3. METHODOLOGY

The methodology includes data gathering such as the targeted number EV vehicles to be manufactured yearly and the data related to distribution system capacity and generation capacity. The data analysis and simulation is done by using MATLAB and ETAP software. In this software the charging characteristics of EV is studied and the best charging time is selected taking into account of factors such as utility cost, availability of renewables and distributed resources, vehicle densities among others. The result should be identification of potential magnitude of electrical vehicles to be connected at specific busses depending to the energy required in specific time period, the potential CO2 savings, system stability and harmonic distortion.

3.1 GENERATION CAPACITY

The generation as by 2021 shows that the installed capacity is about 235.6MW including renewables which amounts for 132.778 MW (55.703%) and 103.590 (43.458%) non-renewables. The figure below shows the evolution of installed capacity from 2010 to date.

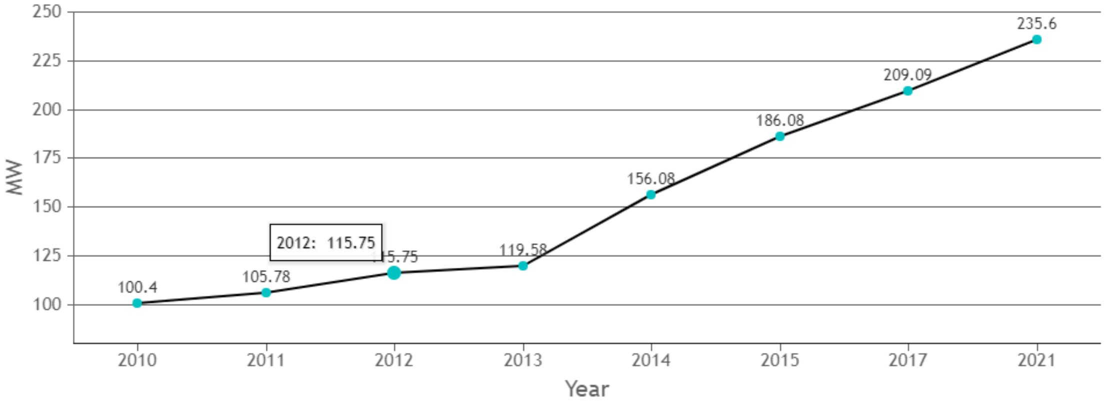


Figure 3.1 Evolution of installed capacity

The nation plan is to expand its grid up to 556 MW in 2024. In line with this plan many new plants are proposed or under construction. These plants are shown in tables below.

Table 3.1 Hydro-electric plant expected to expand the grid

Hydroelectric station	Community	River	Type	Capacity (MW)	Year completed
Rusumo Power Station	Rusumo	Kagera River	Run of river	80	2021
Nyabarongo II Power Station	Nyabarongo	Nyabarongo River	Run of river	43	2024
Rusizi III Power Station	Rusizi	Rusizi River	Run of river	147	2023
Rusizi IV Power Station	Rusizi	Rusizi River	Run of river	287	2025

Table 3.2 Thermal Power plant expected to expand the grid capacity

Thermal Power Station	Community	Fuel type	Capacity (MW)	Year completed	Owner	Notes
Gisagara thermal power station	Gisagara district	Peat	80	2021	Hakan	
Symbion Thermal Power Station	Rubavu District	Methane	50	2018	Symbion Power Inc.	to be expanded to 100MW

3.2 TRANSMISSION CAPACITY

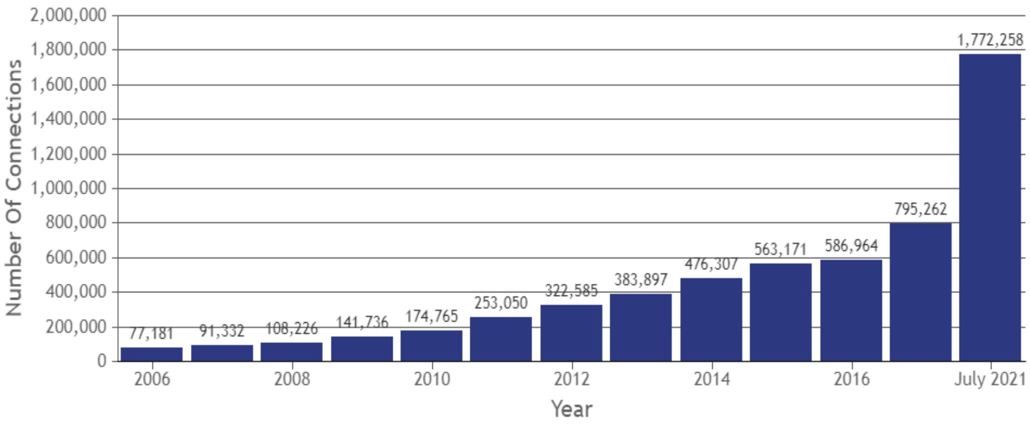
Transmission network in Rwanda has 3 main voltage levels; 70kV, 110kV and 220kV transmission infrastructure. As it stands 777.4 Km of High Voltage (HV) transmission lines had been laid, carrying power from different locations of generation across the country and allowing interconnection with neighboring country. The total length of the lines represents an increase of 4.3% referred to 744.7 Km counted in 2017 above and 35.4% (573.9 Km) in 2016. For the sake of improving network reliability and power supply stability in line with the country's changing power demand profile, 70KV lines have been upgraded to 110KV as a result the current transmission network laid consist of 110kV network amounting 64.5% (480.4 km) and 35.5% (264.3 km) of 220kV transmission network.

3.3 LOAD FORECASTING

The country target of 100% electrification by 2024 in such a way that 65% of all customers are connected to the grid while the remaining 35% are off grid connected. This connection target is growing each year with 3% since Rwandan population growth rate is taken at 3%.

Table 3.3: Load growth from 2017 to 2030

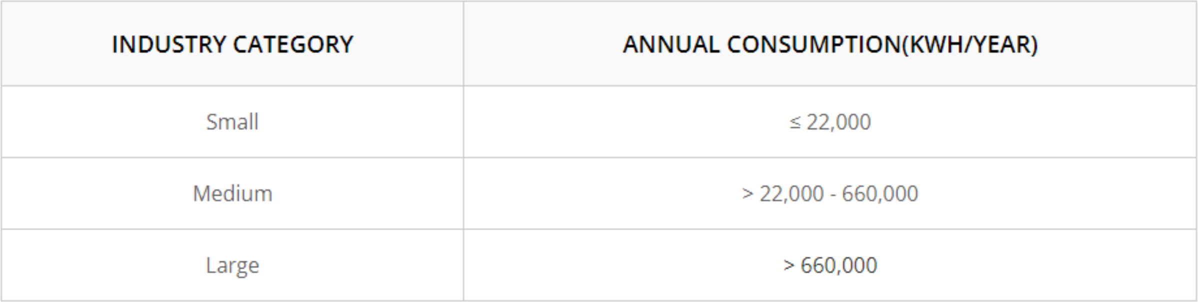
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Growth of existing load Low	0.0%	4.0%	4.0%	4.0%	4.0%	3.5%	3.5%	3.5%	3.0%	3.0%	3.0%	2.5%	2.5%	2.5%
Growth of existing load Med	0.0%	5.0%	5.0%	5.0%	5.0%	4.5%	4.5%	4.5%	4.0%	4.0%	4.0%	3.5%	3.5%	3.5%
Growth of existing load High	0.0%	6.0%	6.0%	6.0%	6.0%	5.5%	5.5%	5.5%	5.0%	5.0%	5.0%	4.5%	4.5%	4.5%



3.4 COST OF ELECTRICITY

The current tariff as issued in 2020 by RURA classifies the customer into two categories viz non-industrial customers and industrial customers. The later are categorized based on their level of consumption defined as follows:

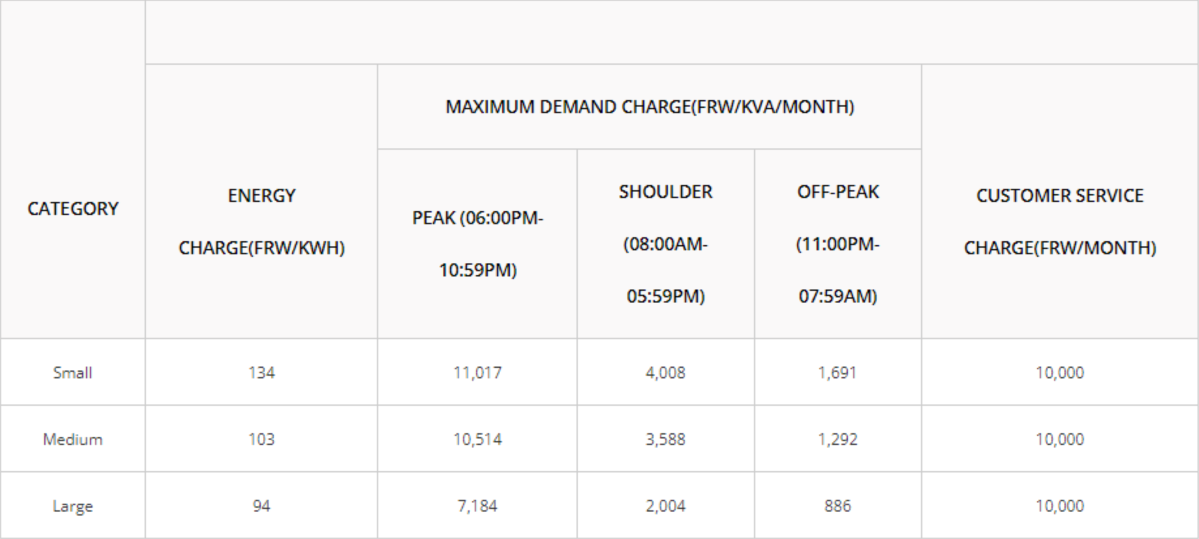
Table 3.4: Categories of industrial customers



INDUSTRY CATEGORY	ANNUAL CONSUMPTION(KWH/YEAR)
Small	≤ 22,000
Medium	> 22,000 - 660,000
Large	> 660,000

These customers are charged on the basis of energy consumption and maximum load issued to the network. The maximum demand charges depend upon the period of connection to the grid as follows:

Table 3.5: Industrial tariff per category



CATEGORY	ENERGY CHARGE(FRW/KWH)	MAXIMUM DEMAND CHARGE(FRW/KVA/MONTH)			CUSTOMER SERVICE CHARGE(FRW/MONTH)
		PEAK (06:00PM-10:59PM)	SHOULDER (08:00AM-05:59PM)	OFF-PEAK (11:00PM-07:59AM)	
Small	134	11,017	4,008	1,691	10,000
Medium	103	10,514	3,588	1,292	10,000
Large	94	7,184	2,004	886	10,000

3.5 CASE STUDY

The data shows the voltage profile of a chosen line from Camp Belge substation in the northern corridor in which distribution transformers distances, phase voltage, current and power consumption on each bus are shown.

Table 3.6: distribution network data for Kinigi feeder

s/N	Substation Name	Line Name	DT Name	Transformer Capacity	Maximum Load	A Phase Voltage (V)	B Phase Voltage (V)	C Phase Voltage (V)	A Phase Current (A)	B Phase Current (A)	C Phase Current (A)	Minimum Load	Max Load Rate (%)	Min Load Rate (%)	Status	DISTANCE (m)
1	CAMP BELGE	KINIGI	CAMP BELGE	630	131.6	234.4	235.9	235.9	0	0	2.824	23.8	20.89	3.78	underloa	0
2	CAMP BELGE	KINIGI	GIKWEGE	250	158.16	235.7	236.3	234.9	2.032	2.58	2.328	27.67	63.26	11.07	normal	400
3	CAMP BELGE	KINIGI	APICUR	500	637.888	252.7	252.4	251.9	6.108	5.662	5.314	133.2	127.58	26.64	overload	800
4	CAMP BELGE	KINIGI	KABEZA	100	169.536	255.6	253.6	253.5	9.808	10.968	9.342	29.91	169.54	29.91	overload	1300
5	CAMP BELGE	KINIGI	5 VOLCANOES HOTEL	250	28.56	232.6	234.3	233.8	0	0	1.636	2.704	11.42	1.08	underloa	900
6	CAMP BELGE	KINIGI	NYANGE	100	87.648	234.5	234.4	233.9	3.164	4.312	4.396	13.0848	87.65	13.08	heavy loa	800
7	CAMP BELGE	KINIGI	KINIGI DISTRICT	400	218	241.9	242.1	241.7	3.86	4.014	4.098	24.816	54.5	6.2	normal	1400
8	CAMP BELGE	KINIGI	GORILLA NEST	100	21.86	240.2	240.6	240.7	1.278	0.536	0.616	4.21	21.86	4.21	underloa	600
9	CAMP BELGE	KINIGI	GASURA	50	47.264	239.2	239.1	238.6	0.816	1.414	0.66	9.088	94.53	18.18	heavy loa	700
10	CAMP BELGE	KINIGI	MOUNTAIN GORILLA	100	82.504	237.5	237.2	237.2	3.008	2.866	4.772	7.58	82.5	7.58	heavy loa	1100
11	CAMP BELGE	KINIGI	SACCOLA	100	13.5744	243.5	243.2	242.6	0	0	1.782	3.1296	13.57	3.13	underloa	1200
12	CAMP BELGE	KINIGI	KURIMIRONGWINE	25	12.3472	255.4			32			1.7752	49.39	7.1	normal	1600
13	CAMP BELGE	KINIGI	BINGO LOW	25	14.0594	249.1			23			1.9624	56.24	7.85	normal	600
14	CAMP BELGE	KINIGI	KAGANO	50	77.3314	242.5	242.7	241.4	1.75	2.63	2.446	32.87	154.66	5.03	overload	
15	CAMP BELGE	KINIGI	KANSORO CENTER	50	51.937	235.1	234.5	233.1	113.532	116.778	102.37	2.517	103.87	11.29	overload	
16	CAMP BELGE	KINIGI	GASIZA	100	75.4836	2021-09-2	231.9	230.7	227.7	188.154	199.69	233.432	3.4959	3.5	normal	

Table 3.7: battery characteristics for EV available in Rwanda

type	Nominal voltage (V)	Nominal active power (kW)	Energy (kWh)	Charging period	Range(fully charged)
e-golf	Single phase 240	7.2	35.8	<6 hours	230 km
VW's new ID3 models	240 single phase 400 three phase	125 kW	58 kWh or 77 kWh	30min	600 km

4. RESEARCH DESIGN

4.1 DESIGN OF EV POWER SUPPLY

For successful operation of EV charging, an appropriate charger should be designed or selected to meet with EV battery properties and characteristics. There are varieties of EV batteries and the researcher identified some of them available and being used in the selected study case.

Since the battery is charged through AC distribution supply, a controlled rectifier is required to convert AC to DC necessary to charge the battery. The output of the rectifier may not be in line with the battery nominal voltage and hence a buck converter is used to lower the voltage to the specific battery voltage. This configuration is taken as grid to vehicle (G2V) model.

In some application, EV battery may be used to cope with load flics and unbalance between generation and load demand or even to shift the peak load period, for this purpose the stored energy in the battery is sold back to the grid. To be able to serve for this purpose, the rectifier should be an h-bridge bidirectional converter and a boost converter is added to the configuration and the latter becomes vehicle to grid (V2G) model.

The battery charger is a non-linear load and results in harmonic distortion of the signal which in produces EMI in neighborhood communication lines and transformer saturation. A smoothing inductor is added to the configuration to reduce the effect of harmonics produced during charging and discharging process. The power circuit of both configurations is shown and matlab Simulink software is used for modelling of EV charger.

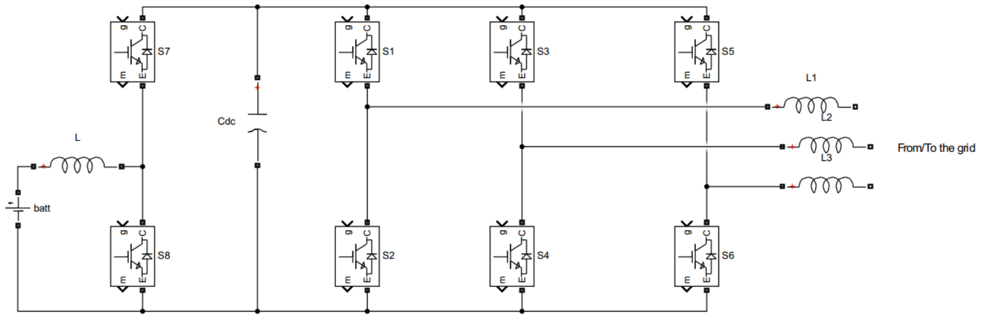


Figure 4.1 Rectifier/ Inverter circuit

4.1.1 BATTERY SPECIFICATIONS

Battery capacity	35.8kWh
Number of cells	264
Number of modules	27
Voltage	323
Type of charging	slow Fast

4.1.2 GRID SPECIFICATIONS

Nominal Voltage	Vnom	400V3phase 240V1phase
Rated power	Prated	11KW
Nominal frequency	Fnom	50Hz

4.1.3 RECTIFIER OUTPUT

The output voltage of the 6 pulses rectifier by using IGBT as power switching devices, was obtained with the help of the following formulae [9] [10],

$$V_{DC} = 1.35V_{rms}\cos\alpha$$

Since IGBTs are used as switching devices, $V_{DC} = 1.35V_{rms}$

4.1.4 BUCK CONVERTER OUTPUT

The unfiltered DC output of the rectifier is fed to a buck-boost converter to form a bilateral network since EVs can be used in both G2V and V2G configurations.

4.1.5 SMOOTHING INDUCTOR

The magnitude of switching ripple in the output voltage in a properly constructed DC supply is substantially less than the dc component. As a result, the dc component of the output voltage is approximated, and the value of the inductor may be computed using the inductor's defining equation [11].

$$L\frac{di}{dt} = V_L \qquad (1)$$

For electric vehicle, it was found that a DC-link voltage of 650 V would be most suitable for the battery charger. Since the DC link voltage is 650V, the battery voltage becomes 325V. By summing all components, $V_{dc} = V_L + V_{batt}$

$$V_L = V_{dc} - V_{batt}$$

$$L_{batt} = \frac{(V_{dc} - V_{batt})\Delta t}{\Delta i} \qquad (2)$$

The step size Δt is a half of switching period and Δi is twice the maximum ripple current because the output voltage is a half of the input voltage.

That is

$$L_{batt} = \frac{(650 - 325)\frac{1}{2f_{sw}}}{10}$$

$$L_{batt} = \frac{16.25}{f_{sw}}$$

For a switching frequency of 10kHz,

$$L_{batt} = 1.6mH$$

4.1.6 DC CAPACITOR

The criterion for no ripples in the capacitor voltage has been relaxed to allow for a little amount of ripple. For successful periodic operation, the current through the capacitor must be completely alternating at all times. The resulting ripple in the capacitor voltage is determined by the area under the curve of the capacitor current versus time while the addition charge to the capacitor in a half-cycle is obtained from the triangular area above the axis as shown below [11].

$$\Delta Q = \frac{1}{2}\frac{I_{max} - I_{min}}{2}\frac{T}{2} = \frac{I_{max} - I_{min}}{8}T \qquad (3)$$

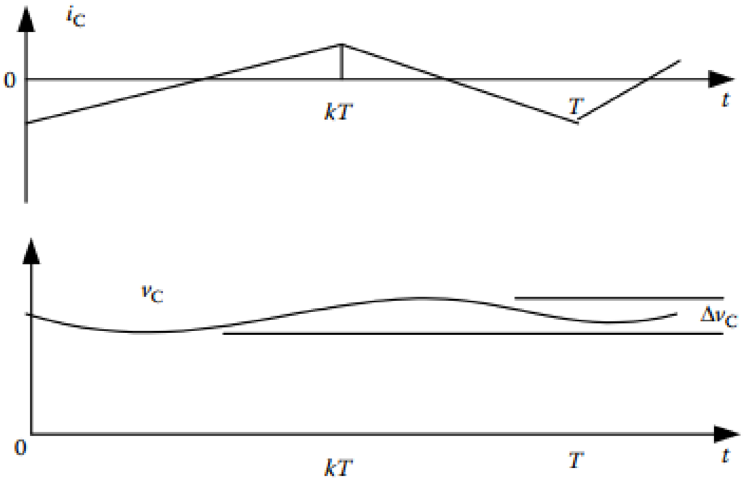


Figure 4.2 Waveforms of ic and vc

The peak to peak ripple voltage, $\Delta V_c = \frac{\Delta Q}{C} = \frac{I_{max} - I_{min}}{8C} T = \frac{D(1-D)V_{batt}}{8CL} T^2$

$$C = \frac{D(1-D)V_{batt}}{8L\Delta V_c} T^2 \qquad (4)$$

According to standard, during cycle service charging, the maximum permissible ripple voltage should be limited to 1.5 % rms of the charging voltage. Putting the value of ripple voltage, battery voltage, inductance, duty cycle and switching frequency,

C =130 nF

4.1.7 GRID SIDE INDUCTOR

The value of grid side inductance can be obtained by considering the Total Harmonic Distortion (THD) given by $THD = \frac{\sqrt{\sum_H^\infty (\frac{1}{L} . \frac{1}{2\pi f_1} . \frac{V_{L,h}}{h})^2}}{I_{1,h}} = \frac{\frac{1}{L} . \frac{1}{2\pi f_1} \sqrt{\sum_H^\infty (\frac{V_{L,h}}{h})^2}}{I_{1,n}}$ (5)

By considering IEC standards, the maximum AC ripples should not exceed 0.6%.By using matlab code to solve for inductance in equation 4.5, $L_{ac} = 30.2\ mH$

4.1.8 ELECTRIC VEHICLE BATTERY CHARGER UNIT

It consists of one IGBT switch for buck and another for boost conversion operating modes with the required gate control signals and serves as DC to DC converter. During charging operation, the buck converter switch is active while the boost converter switch remains idle. During discharging when there is a need to sell back power to the grid, the boost converter switch is active while the buck converter switch remains idle.

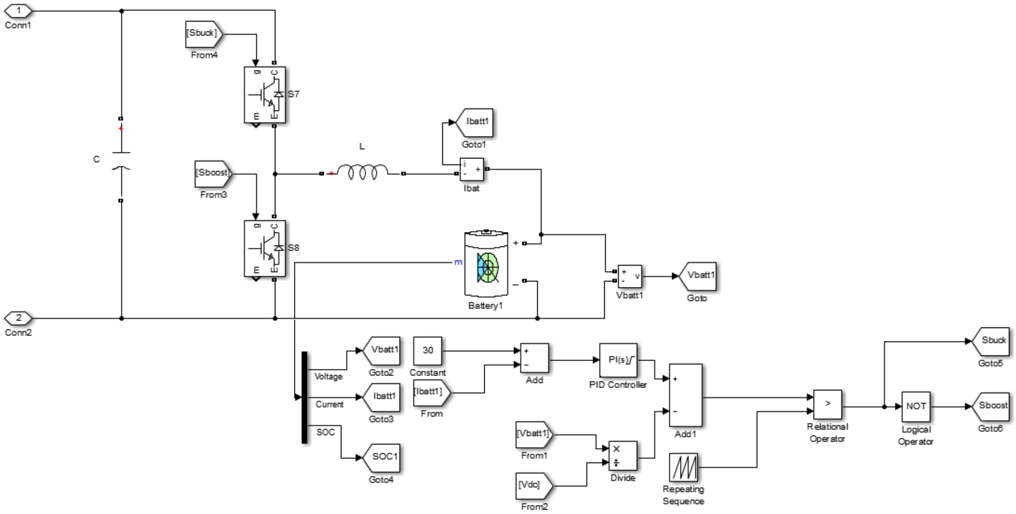


Figure 4.3 The converter Simulink circuit and its gate control

4.1.9 THE CONTROL CIRCUIT FOR BI-DIRECTIONAL INVERTER

The unit consists of PWM generator controlled via voltage control loop to provide necessary pulses for triggering 6 switches used as converter switches.

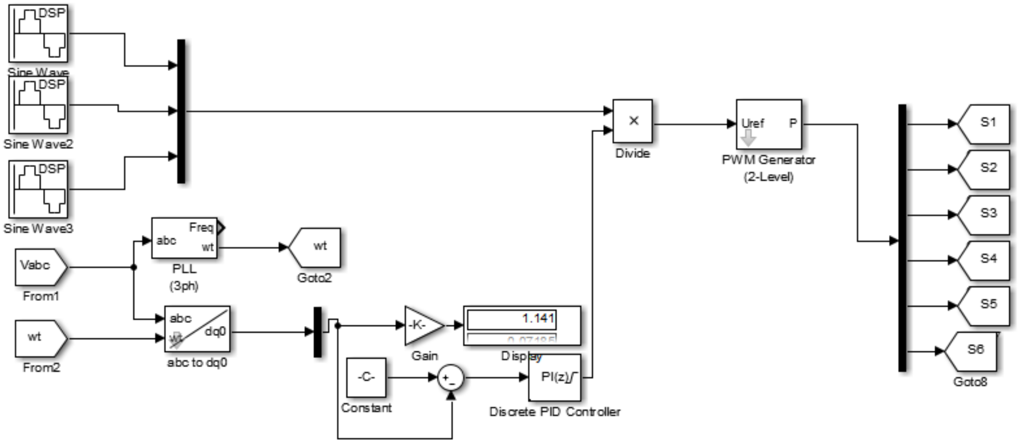


Figure 4.4 Rectifier/ Inverter gates control circuit

4.2 EFFECT OF ELECTRIC CHARGING STATION ON VOLTAGE PROFILE

The model is taken at Camp belge substation in northern corridor of Rwandan network and the study is carried out at Kinigi feeder which is a 33KV line with 34 voltage buses.

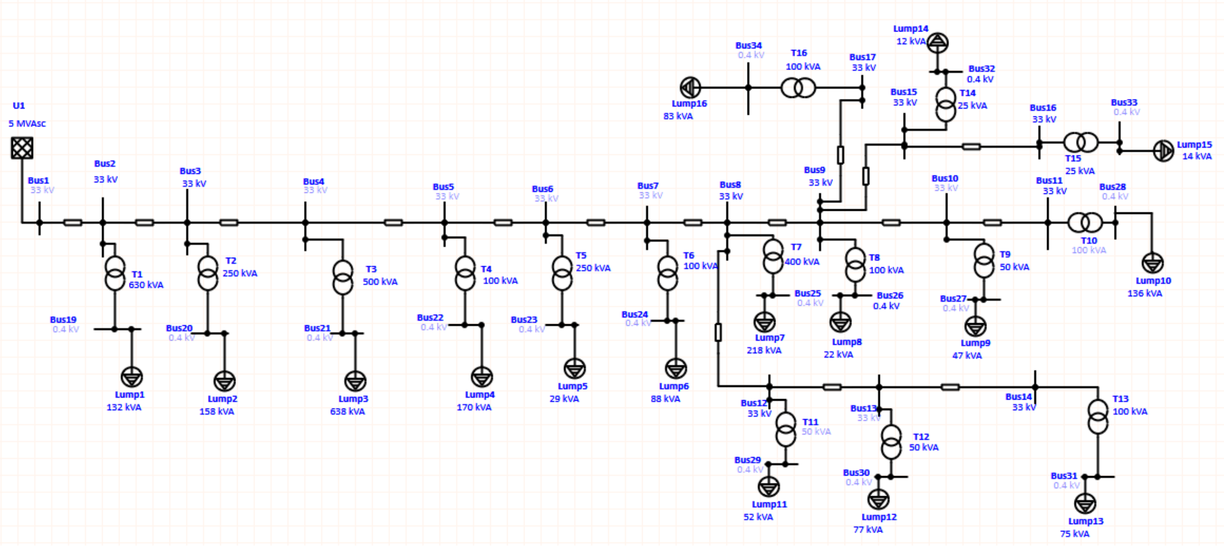


Figure 4.5 Distribution line model

4.2.1 DISTRIBUTION VOLTAGE STABILITY

The power system engineers face voltage stability concerns for many years. The capacity of a power system to maintain steady acceptable voltages at all system buses during normal operating conditions and when an external disturbance is applied is known as voltage stability. When there are voltage instability phenomena, the network bus voltage lessens progressively and uncontrollably. Usually, unstable state is due to the sudden disturbances, fault conditions, single or multiple contingencies, line overloading or load increases. The voltage of all system buses must be within acceptable bounds, according to a voltage stability criterion commonly employed in stability studies. Voltage stability is a local phenomenon, although it can lead to significant voltage breakdown in specific instances. In this work VSI are used to analyze the system voltage stability.

4.2.1.1 VOLTAGE SENSITIVITY FACTOR (VSF)

It is one of the voltage stability indicators obtained from the PV curve which shows the trend of voltage alteration with rising active power as shown in the figure below. To plot the PV curve, the voltage of all buses in the system should be determined by using one of the load flow analysis method.

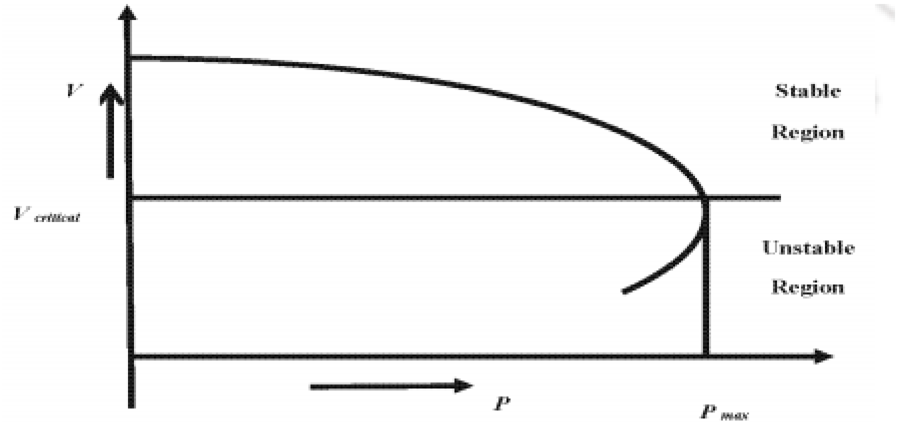


Figure 4.6 Bus PV curve

On the PV curve, the voltage decreases as the active power increases up to the critical point $(P_{max}, V_{critical})$ corresponding to the limit of stable operation. The ratio of change in voltage and change in loading is called VSF expressed mathematically as,

$$\mathrm{VSF} = \left|\frac{\mathrm{dV}}{\mathrm{dP}}\right| \ \forall \mathrm{P} < \mathrm{P_{max}}$$

A high value of VSF indicates that there is a considerable voltage drop thereby signifying weakness of the bus even for a small change in loading. For a distribution network to be stable in terms of voltage stability, the voltage of all buses must be within an acceptable limit. The loading corresponding to this voltage range is called the realistic loading margin of the system.

4.2.1.2 VOLTAGE STABILITY INDEX

A voltage stability analysis usually yields some stability margins or indices, which allow system planners and operators to secure additional reactive power sources if the margin goes below a specific threshold or the index falls into an undesired range.

4.2.2 HARMONIC DISTORTION

Electric vehicle charger is one of nonlinear types of load on distribution network. This type of load affects the power quality of the power system due to the current it draws from the system which is not a perfect sine wave. Since the current waveform deviates from a sinusoidal waveform, the voltage waveform is distorted. Electrical energy consumers are responsible for not lowering the utility's voltage by drawing heavy nonlinear or distorted currents [11][12].

4.2.2.1 TOTAL HARMONIC DISTORTION (THD)

Electric Vehicles utilize power electronics within the charge controllers that link the vehicle's electric system with the grid. For Level I and Level II chargers, an on-board AC-DC controlled rectifier couples with the electric service via a single-phase connector to charge the vehicle. For Level III charges (DC Fast Chargers), electronics in the charge controller control the charging process. In all cases, the charge controllers' harmonic distortion introduced into the distribution network is assessed in terms of THD. Normally the charger THD changes in accordance with the charging cycle as the firing angles of the power electronics switches alter in reaction to the various phases of the charging cycle. Further, the THD on a utility feeder builds up when many EVs are plugged into the same service. The following equation shows how to compute the THD for individual charger. [11][12][13].

$$I_{THD} = \frac{\sqrt{\sum_{n=2} I_n^2}}{I_1} * 100\%$$

The harmonic distortion impacts distribution devices, especially capacitors, metering, transformers, power cables, relaying and switchgear as well as nearby loads, particularly power electronics devices and motors drives.

The standardized value of the maximum level of THD to be adopted for planning, development and connections on the distribution network are given in the table below.

Table 4.1: THD planning limits[14][15]

System voltage	THD limit
400V	5%
6.6kV, 11kV and 20kV	4%
22kV to 400kV	3%

4.2.3 POWER LOSS

The losses in electrical distribution consist of technical and non-technical losses. Technical losses are made of fixed technical losses and variable technical losses and refer to the conductors’ energy dissipation, used power lines equipment and magnetic losses in the transformers. They are directly dependent on the grid characteristics and the mode of operation [11].

The contribution of variable losses ranges from 66 to 75% of total losses on distribution network and consist mainly with Cu losses which vary with the quantity of electricity distributed. The mathematical expression for calculating the line losses at bus j is given in the following equation [16].

$$P_j = I^2 r \qquad (6)$$

And the total power losses of a distribution system of n busses are given by

$$P_t = \sum_{j=1}^{n} P_j \qquad (7)$$

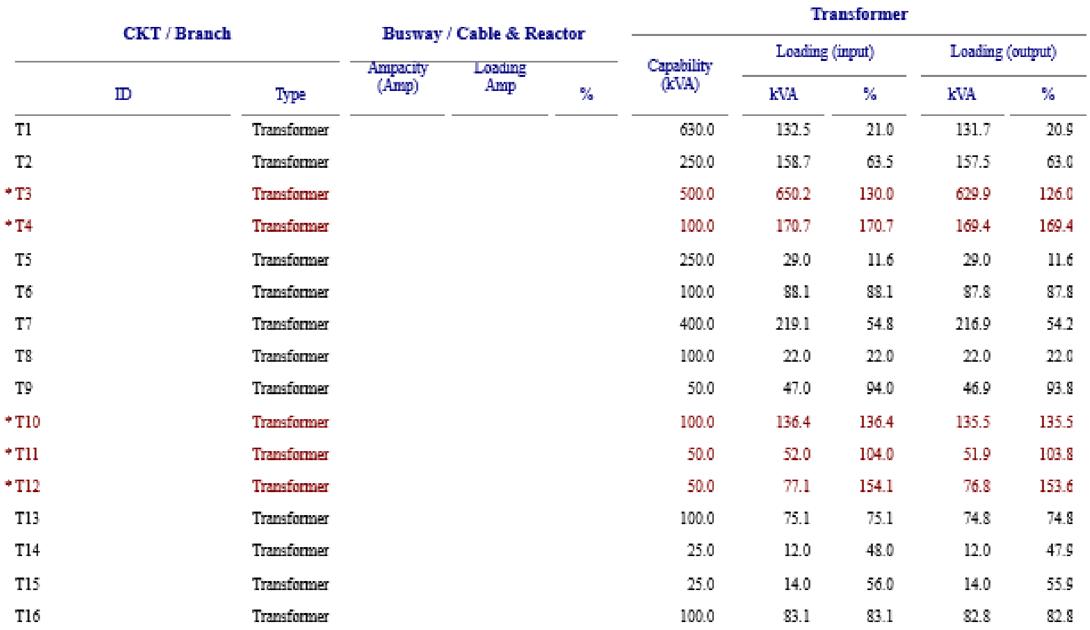
From the above equation, we can conclude that even a single bus's rise in load demand will result in a net increase in distribution network power losses.

5. SIMULATION AND RESULTS

5.1 TRANSFORMER LOADING

Transformer loading is simulated by using ETAP software to show he status of output power at different buses as percentage of the input power supplied to the specific bus.

Table 5.1: transformer loading



CKT / Branch		Busway / Cable & Reactor			Transformer				
						Loading (input)		Loading (output)	
ID	Type	Ampacity (Amp)	Loading Amp	%	Capability (kVA)	kVA	%	kVA	%
T1	Transformer				630.0	132.5	21.0	131.7	20.9
T2	Transformer				250.0	158.7	63.5	157.5	63.0
*T3	Transformer				500.0	650.2	130.0	629.9	126.0
*T4	Transformer				100.0	170.7	170.7	169.4	169.4
T5	Transformer				250.0	29.0	11.6	29.0	11.6
T6	Transformer				100.0	88.1	88.1	87.8	87.8
T7	Transformer				400.0	219.1	54.8	216.9	54.2
T8	Transformer				100.0	22.0	22.0	22.0	22.0
T9	Transformer				50.0	47.0	94.0	46.9	93.8
*T10	Transformer				100.0	136.4	136.4	135.5	135.5
*T11	Transformer				50.0	52.0	104.0	51.9	103.8
*T12	Transformer				50.0	77.1	154.1	76.8	153.6
T13	Transformer				100.0	75.1	75.1	74.8	74.8
T14	Transformer				25.0	12.0	48.0	12.0	47.9
T15	Transformer				25.0	14.0	56.0	14.0	55.9
T16	Transformer				100.0	83.1	83.1	82.8	82.8

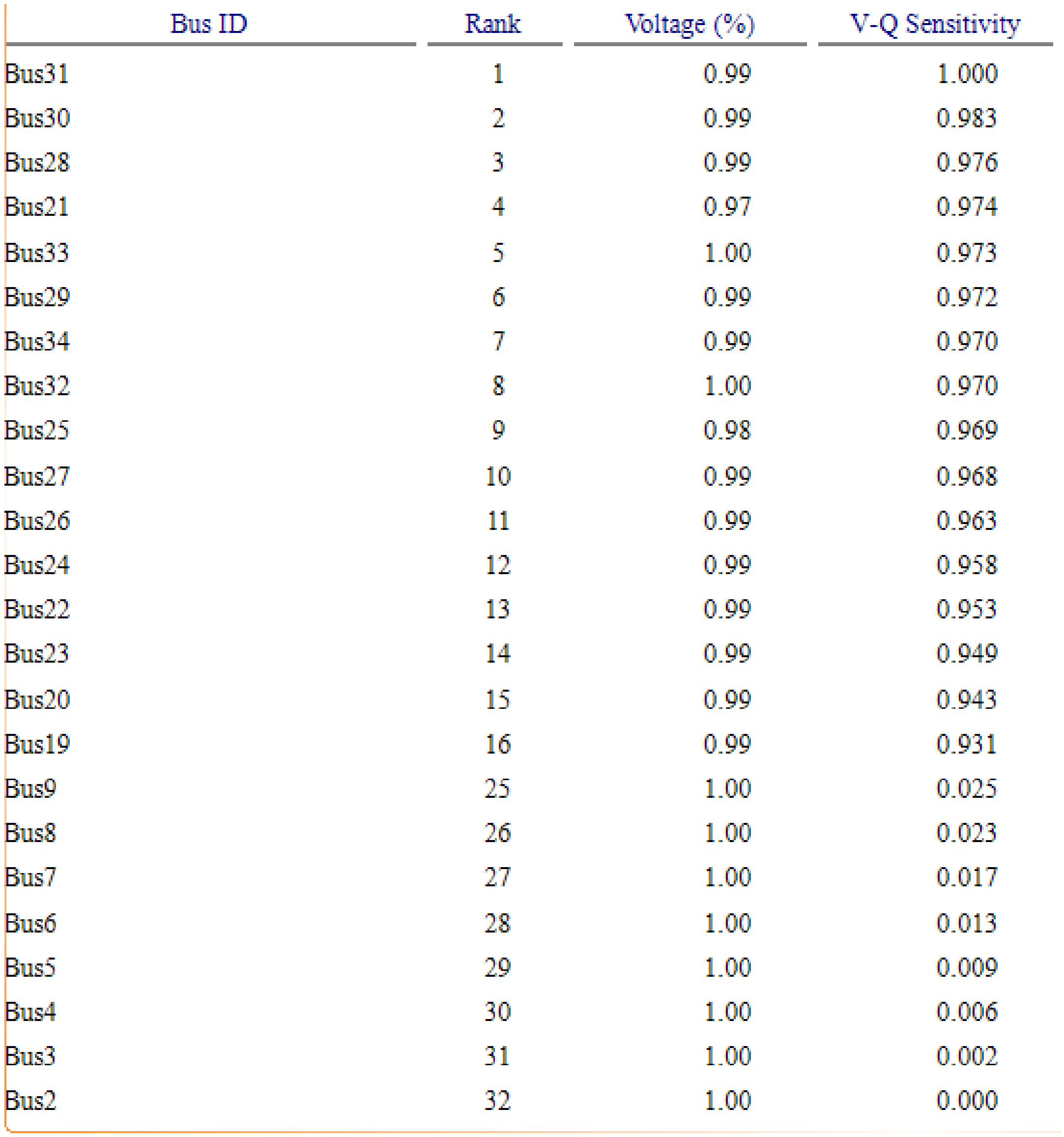
The results show that transformers T3, T4, T10, T11 and T12 are already overloaded referring to their loading capability. Taking into consideration this fact, it is not a good idea to connect an EV at their buses. Hence addition load from EV can be integrated in the network through assessment of the remaining transformers.

5.2 VOLTAGE STABILITY

Table 5.2: V-Q Sensitivity Analysis Report without EV

Bus ID	Rank	Voltage (%)	V-Q Sensitivity
Bus31	1	0.99	1.000
Bus30	2	0.99	0.983
Bus28	3	0.99	0.976
Bus21	4	0.97	0.975
Bus33	5	1.00	0.973
Bus29	6	0.99	0.972
Bus25	7	0.99	0.970
Bus34	8	0.99	0.970
Bus32	9	1.00	0.970
Bus27	10	0.99	0.968
Bus26	11	1.00	0.963
Bus24	12	0.99	0.959
Bus22	13	0.99	0.953
Bus23	14	1.00	0.951
Bus20	15	0.99	0.944
Bus19	16	0.99	0.933
Bus9	25	1.00	0.025
Bus8	26	1.00	0.023
Bus7	27	1.00	0.017
Bus6	28	1.00	0.013
Bus5	29	1.00	0.010
Bus4	30	1.00	0.006
Bus3	31	1.00	0.002
Bus2	32	1.00	0.000

Table 5.3: V-Q Sensitivity Analysis Report with EVs

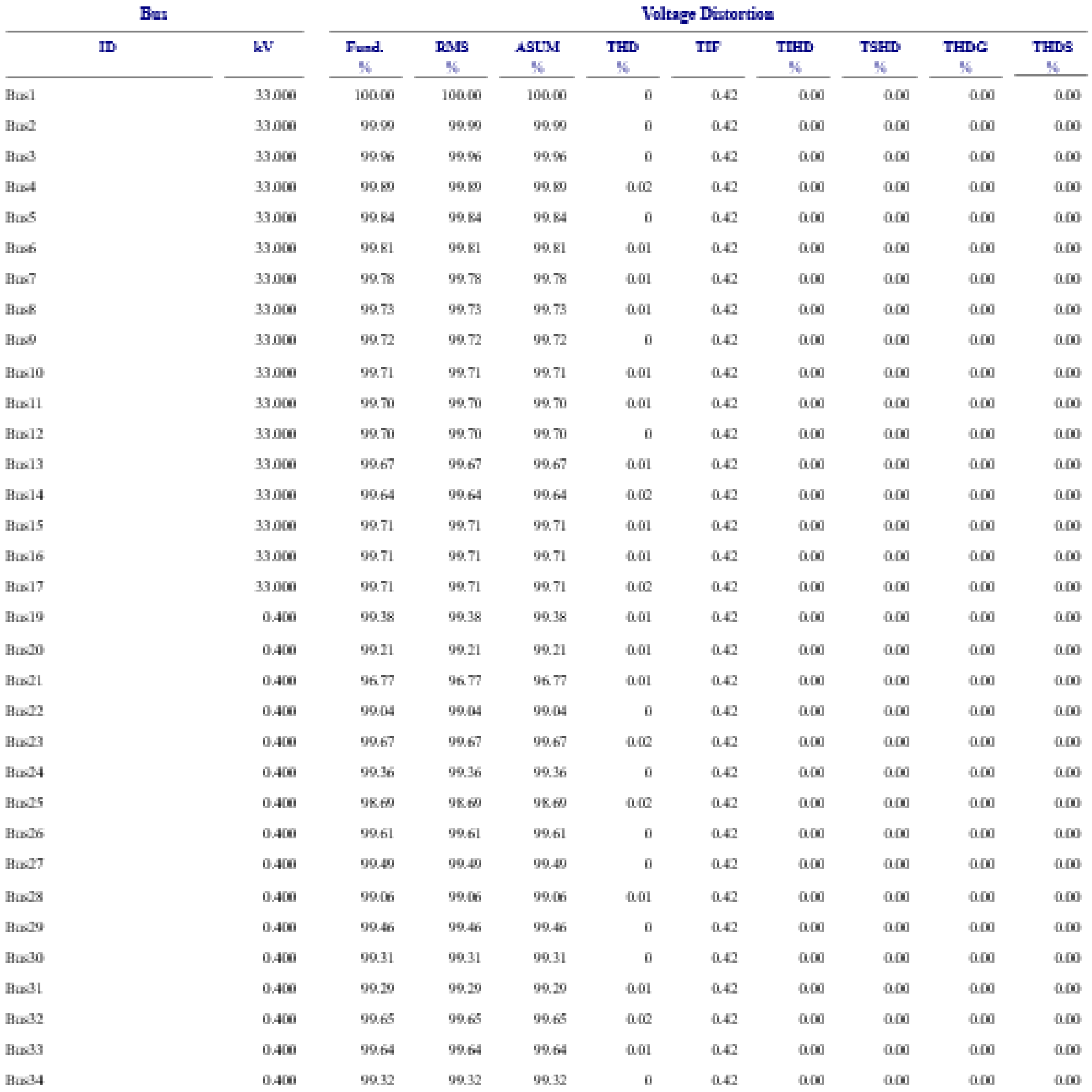


Bus ID	Rank	Voltage (%)	V-Q Sensitivity
Bus31	1	0.99	1.000
Bus30	2	0.99	0.983
Bus28	3	0.99	0.976
Bus21	4	0.97	0.974
Bus33	5	1.00	0.973
Bus29	6	0.99	0.972
Bus34	7	0.99	0.970
Bus32	8	1.00	0.970
Bus25	9	0.98	0.969
Bus27	10	0.99	0.968
Bus26	11	0.99	0.963
Bus24	12	0.99	0.958
Bus22	13	0.99	0.953
Bus23	14	0.99	0.949
Bus20	15	0.99	0.943
Bus19	16	0.99	0.931
Bus9	25	1.00	0.025
Bus8	26	1.00	0.023
Bus7	27	1.00	0.017
Bus6	28	1.00	0.013
Bus5	29	1.00	0.009
Bus4	30	1.00	0.006
Bus3	31	1.00	0.002
Bus2	32	1.00	0.000

V-Q sensitivity increases with increase in loading on the system, hence the integration of EVs has a limited value in other to keep the system stable since if the sensibility exceeds the limits at least from one buses the whole system becomes unstable with a possibility of system collapse once this condition persist.

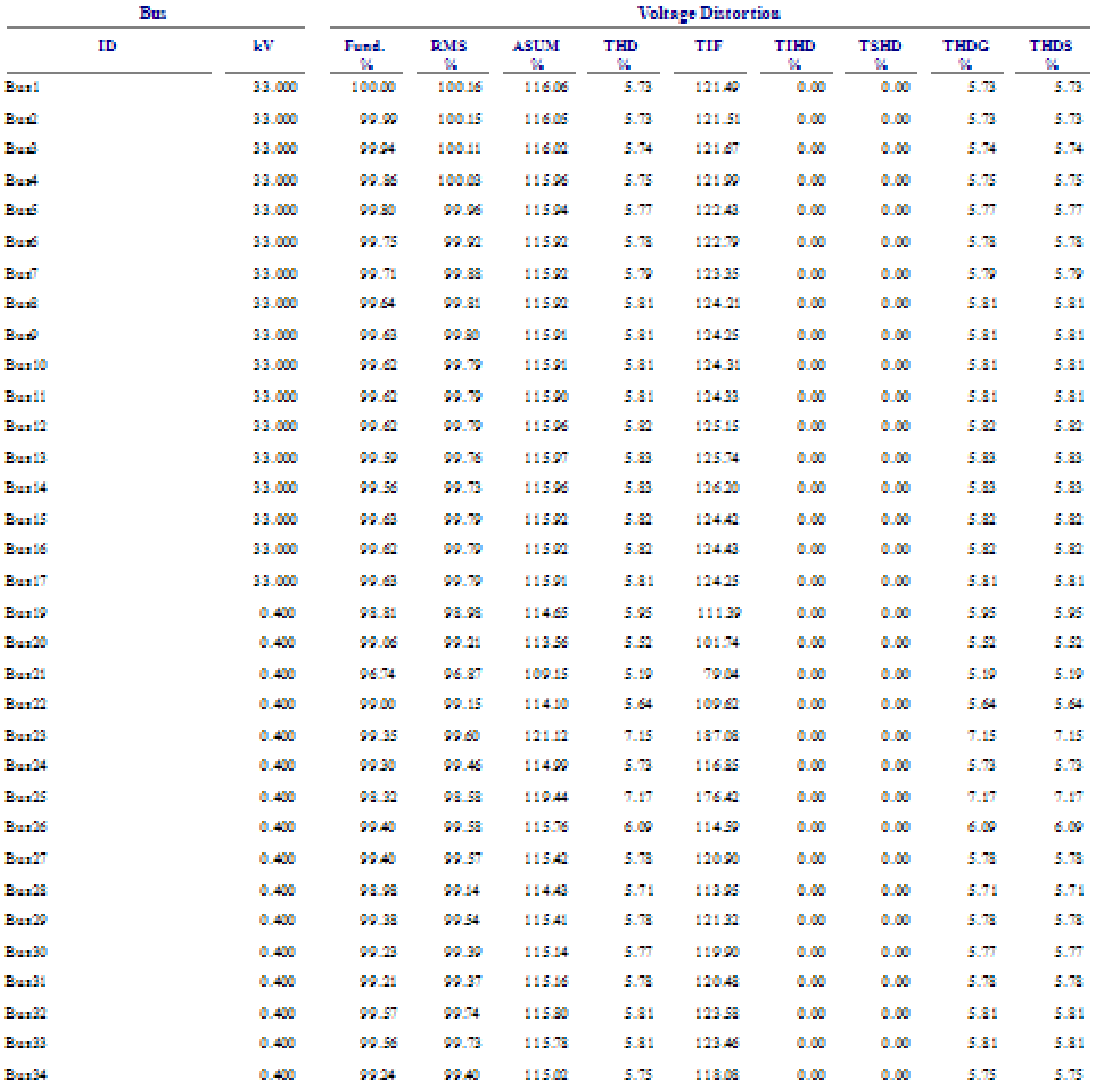
5.3 HARMONIC DISTORTION

Table 5.4: System harmonics buses information after EV integration



Bus		Voltage Distortion								
ID	kV	Fund. %	RMS %	ASUM %	THD %	TIF	TIHD %	TSHD %	THDG %	THDS %
Bus1	33.000	100.00	100.00	100.00	0	0.42	0.00	0.00	0.00	0.00
Bus2	33.000	99.99	99.99	99.99	0	0.42	0.00	0.00	0.00	0.00
Bus3	33.000	99.96	99.96	99.96	0	0.42	0.00	0.00	0.00	0.00
Bus4	33.000	99.89	99.89	99.89	0.02	0.42	0.00	0.00	0.00	0.00
Bus5	33.000	99.84	99.84	99.84	0	0.42	0.00	0.00	0.00	0.00
Bus6	33.000	99.81	99.81	99.81	0.01	0.42	0.00	0.00	0.00	0.00
Bus7	33.000	99.78	99.78	99.78	0.01	0.42	0.00	0.00	0.00	0.00
Bus8	33.000	99.73	99.73	99.73	0.01	0.42	0.00	0.00	0.00	0.00
Bus9	33.000	99.72	99.72	99.72	0	0.42	0.00	0.00	0.00	0.00
Bus10	33.000	99.71	99.71	99.71	0.01	0.42	0.00	0.00	0.00	0.00
Bus11	33.000	99.70	99.70	99.70	0.01	0.42	0.00	0.00	0.00	0.00
Bus12	33.000	99.70	99.70	99.70	0	0.42	0.00	0.00	0.00	0.00
Bus13	33.000	99.67	99.67	99.67	0.01	0.42	0.00	0.00	0.00	0.00
Bus14	33.000	99.64	99.64	99.64	0.02	0.42	0.00	0.00	0.00	0.00
Bus15	33.000	99.71	99.71	99.71	0.01	0.42	0.00	0.00	0.00	0.00
Bus16	33.000	99.71	99.71	99.71	0.01	0.42	0.00	0.00	0.00	0.00
Bus17	33.000	99.71	99.71	99.71	0.02	0.42	0.00	0.00	0.00	0.00
Bus19	0.400	99.38	99.38	99.38	0.01	0.42	0.00	0.00	0.00	0.00
Bus20	0.400	99.21	99.21	99.21	0.01	0.42	0.00	0.00	0.00	0.00
Bus21	0.400	96.77	96.77	96.77	0.01	0.42	0.00	0.00	0.00	0.00
Bus22	0.400	99.04	99.04	99.04	0	0.42	0.00	0.00	0.00	0.00
Bus23	0.400	99.67	99.67	99.67	0.02	0.42	0.00	0.00	0.00	0.00
Bus24	0.400	99.36	99.36	99.36	0	0.42	0.00	0.00	0.00	0.00
Bus25	0.400	98.69	98.69	98.69	0.02	0.42	0.00	0.00	0.00	0.00
Bus26	0.400	99.61	99.61	99.61	0	0.42	0.00	0.00	0.00	0.00
Bus27	0.400	99.49	99.49	99.49	0	0.42	0.00	0.00	0.00	0.00
Bus28	0.400	99.06	99.06	99.06	0.01	0.42	0.00	0.00	0.00	0.00
Bus29	0.400	99.46	99.46	99.46	0	0.42	0.00	0.00	0.00	0.00
Bus30	0.400	99.31	99.31	99.31	0	0.42	0.00	0.00	0.00	0.00
Bus31	0.400	99.29	99.29	99.29	0.01	0.42	0.00	0.00	0.00	0.00
Bus32	0.400	99.65	99.65	99.65	0.02	0.42	0.00	0.00	0.00	0.00
Bus33	0.400	99.64	99.64	99.64	0.01	0.42	0.00	0.00	0.00	0.00
Bus34	0.400	99.32	99.32	99.32	0	0.42	0.00	0.00	0.00	0.00

Table 5.5: System harmonics buses information after EV integration



Bus		Voltage Distortion								
ID	kV	Fund. %	RMS %	ASUM %	THD %	TIF	TIHD %	TSHD %	THDG %	THDS %
Bus1	33.000	100.00	100.16	116.06	5.73	121.49	0.00	0.00	5.73	5.73
Bus2	33.000	99.99	100.15	116.05	5.73	121.51	0.00	0.00	5.73	5.73
Bus3	33.000	99.94	100.11	116.02	5.74	121.67	0.00	0.00	5.74	5.74
Bus4	33.000	99.86	100.03	115.96	5.75	121.99	0.00	0.00	5.75	5.75
Bus5	33.000	99.80	99.96	115.94	5.77	122.43	0.00	0.00	5.77	5.77
Bus6	33.000	99.75	99.92	115.92	5.78	122.79	0.00	0.00	5.78	5.78
Bus7	33.000	99.71	99.88	115.92	5.79	123.35	0.00	0.00	5.79	5.79
Bus8	33.000	99.64	99.81	115.92	5.81	124.21	0.00	0.00	5.81	5.81
Bus9	33.000	99.63	99.80	115.91	5.81	124.25	0.00	0.00	5.81	5.81
Bus10	33.000	99.62	99.79	115.91	5.81	124.31	0.00	0.00	5.81	5.81
Bus11	33.000	99.62	99.79	115.90	5.81	124.33	0.00	0.00	5.81	5.81
Bus12	33.000	99.62	99.79	115.96	5.82	125.15	0.00	0.00	5.82	5.82
Bus13	33.000	99.59	99.76	115.97	5.83	125.74	0.00	0.00	5.83	5.83
Bus14	33.000	99.56	99.73	115.96	5.83	126.20	0.00	0.00	5.83	5.83
Bus15	33.000	99.63	99.79	115.92	5.82	124.42	0.00	0.00	5.82	5.82
Bus16	33.000	99.62	99.79	115.92	5.82	124.43	0.00	0.00	5.82	5.82
Bus17	33.000	99.63	99.79	115.91	5.81	124.25	0.00	0.00	5.81	5.81
Bus19	0.400	98.81	98.98	114.65	5.95	111.39	0.00	0.00	5.95	5.95
Bus20	0.400	99.06	99.21	113.56	5.52	101.74	0.00	0.00	5.52	5.52
Bus21	0.400	96.74	96.87	109.15	5.19	79.04	0.00	0.00	5.19	5.19
Bus22	0.400	99.00	99.15	114.10	5.64	109.62	0.00	0.00	5.64	5.64
Bus23	0.400	99.35	99.60	121.12	7.15	187.08	0.00	0.00	7.15	7.15
Bus24	0.400	99.30	99.46	114.99	5.73	116.85	0.00	0.00	5.73	5.73
Bus25	0.400	98.32	98.58	119.44	7.17	176.42	0.00	0.00	7.17	7.17
Bus26	0.400	99.40	99.58	115.76	6.09	114.59	0.00	0.00	6.09	6.09
Bus27	0.400	99.40	99.57	115.42	5.78	120.90	0.00	0.00	5.78	5.78
Bus28	0.400	98.98	99.14	114.43	5.71	113.95	0.00	0.00	5.71	5.71
Bus29	0.400	99.38	99.54	115.41	5.78	121.32	0.00	0.00	5.78	5.78
Bus30	0.400	99.23	99.39	115.14	5.77	119.90	0.00	0.00	5.77	5.77
Bus31	0.400	99.21	99.37	115.16	5.78	120.48	0.00	0.00	5.78	5.78
Bus32	0.400	99.57	99.74	115.80	5.81	123.58	0.00	0.00	5.81	5.81
Bus33	0.400	99.56	99.73	115.78	5.81	123.46	0.00	0.00	5.81	5.81
Bus34	0.400	99.24	99.40	115.02	5.75	118.08	0.00	0.00	5.75	5.75

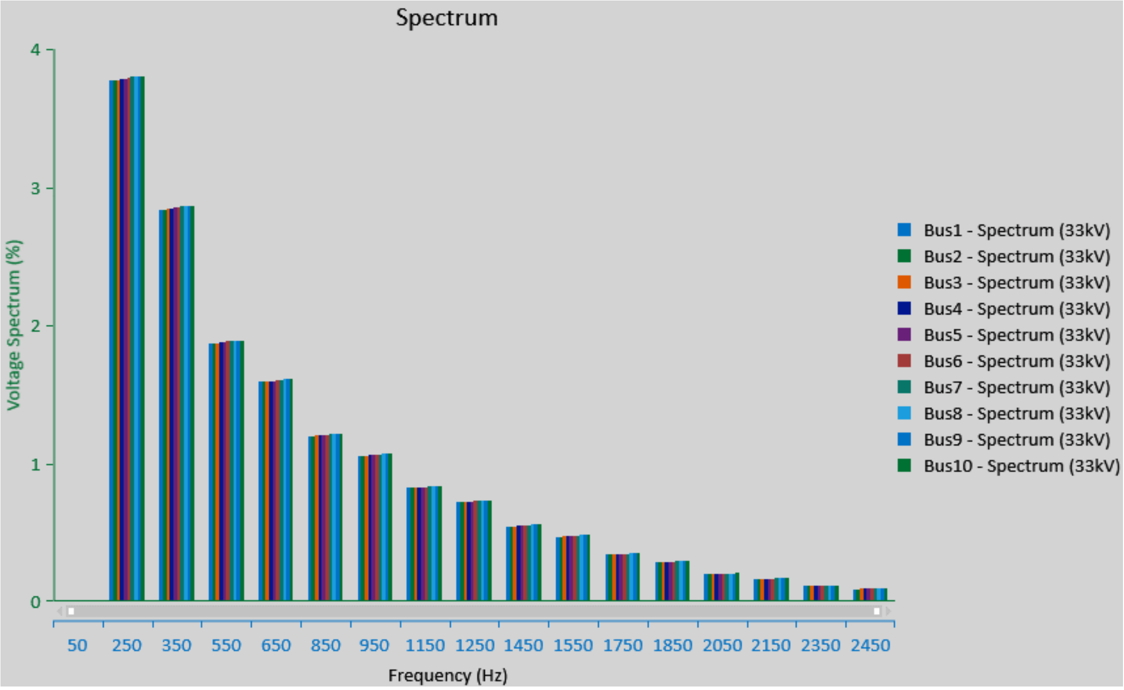


Figure 5.1 Harmonic distortion for buses (from bus 1 to bus 10)

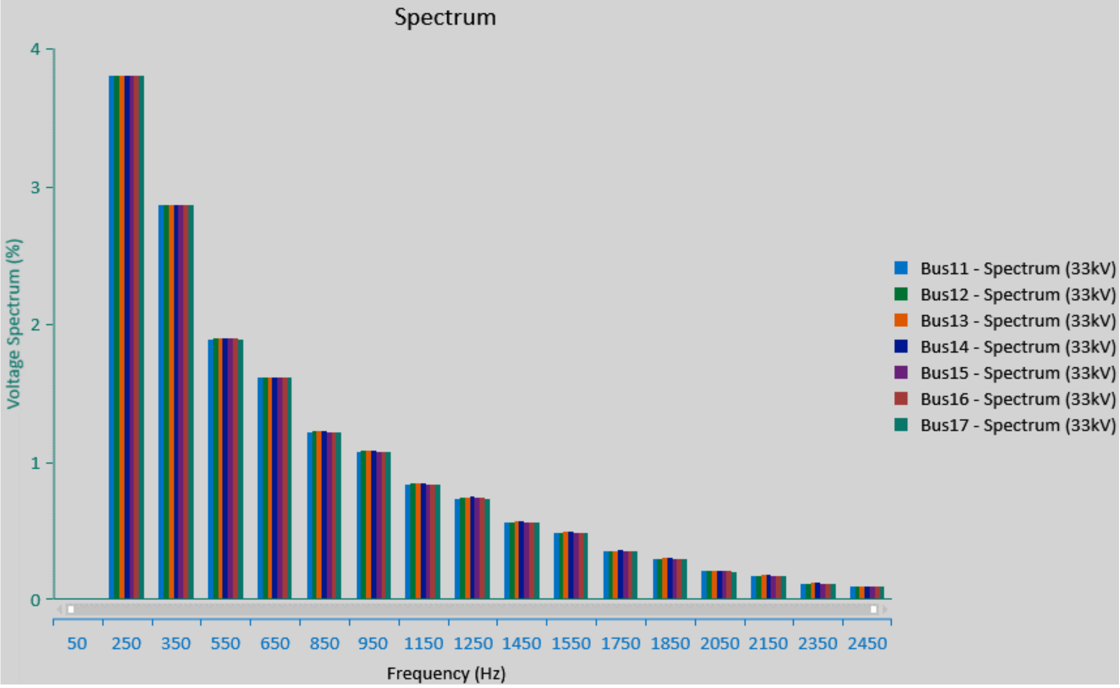


Figure 5.2 Harmonic distortion for buses (from bus 11 to bus 17)

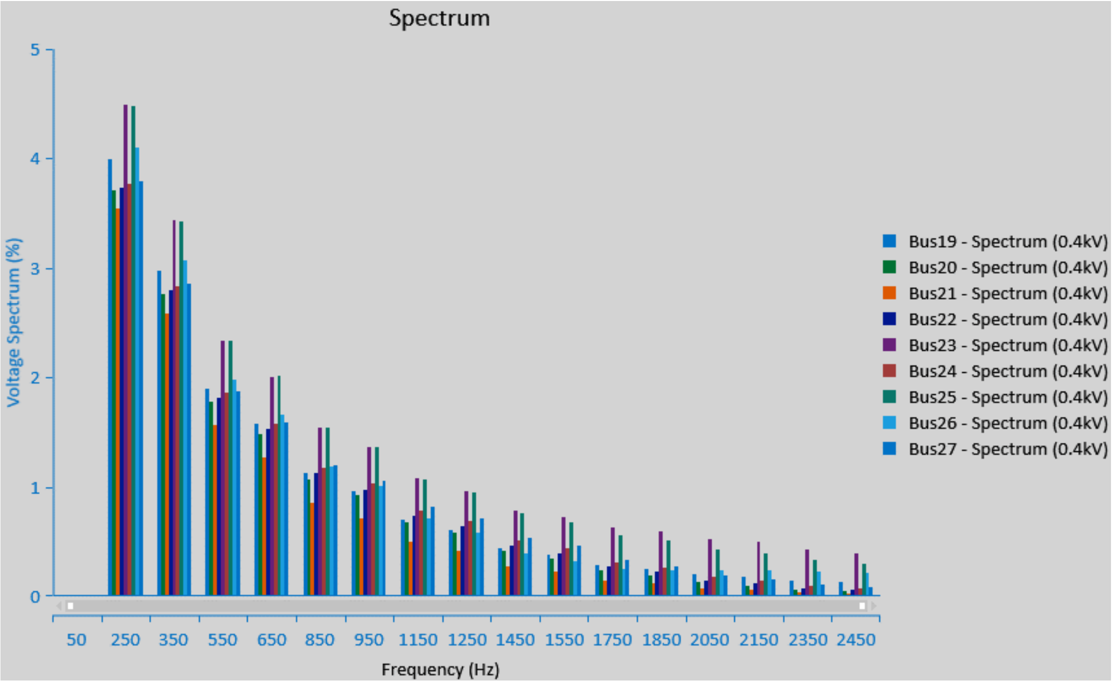


Figure 5.3 Harmonic distortion for buses (from bus 19 to bus 27)

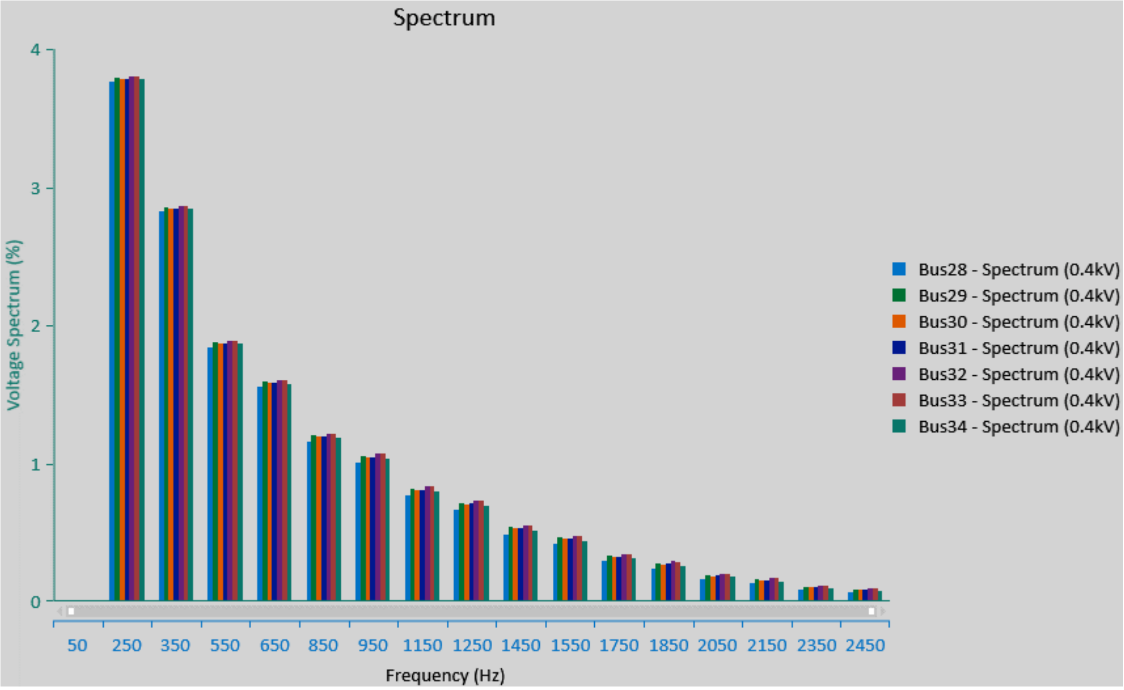


Figure 5.4 Harmonic distortion for buses (from bus 28 to bus 34)

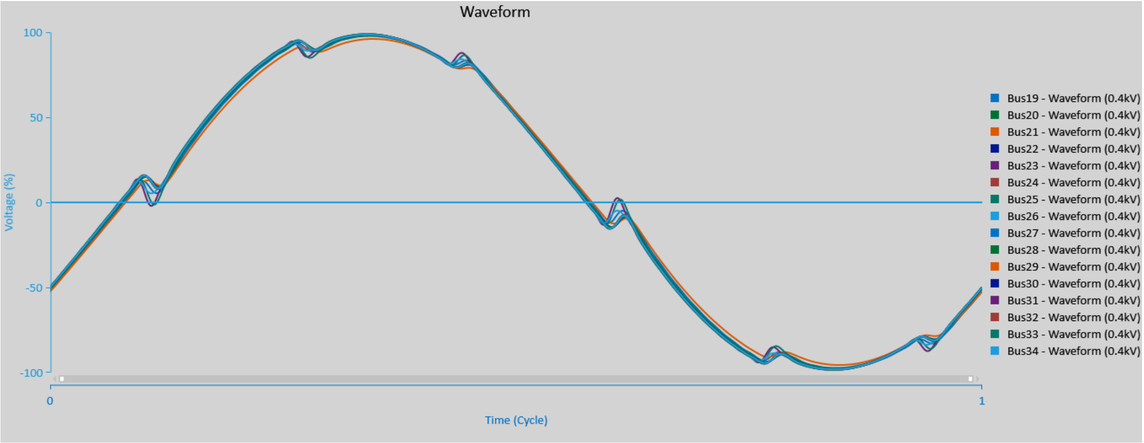
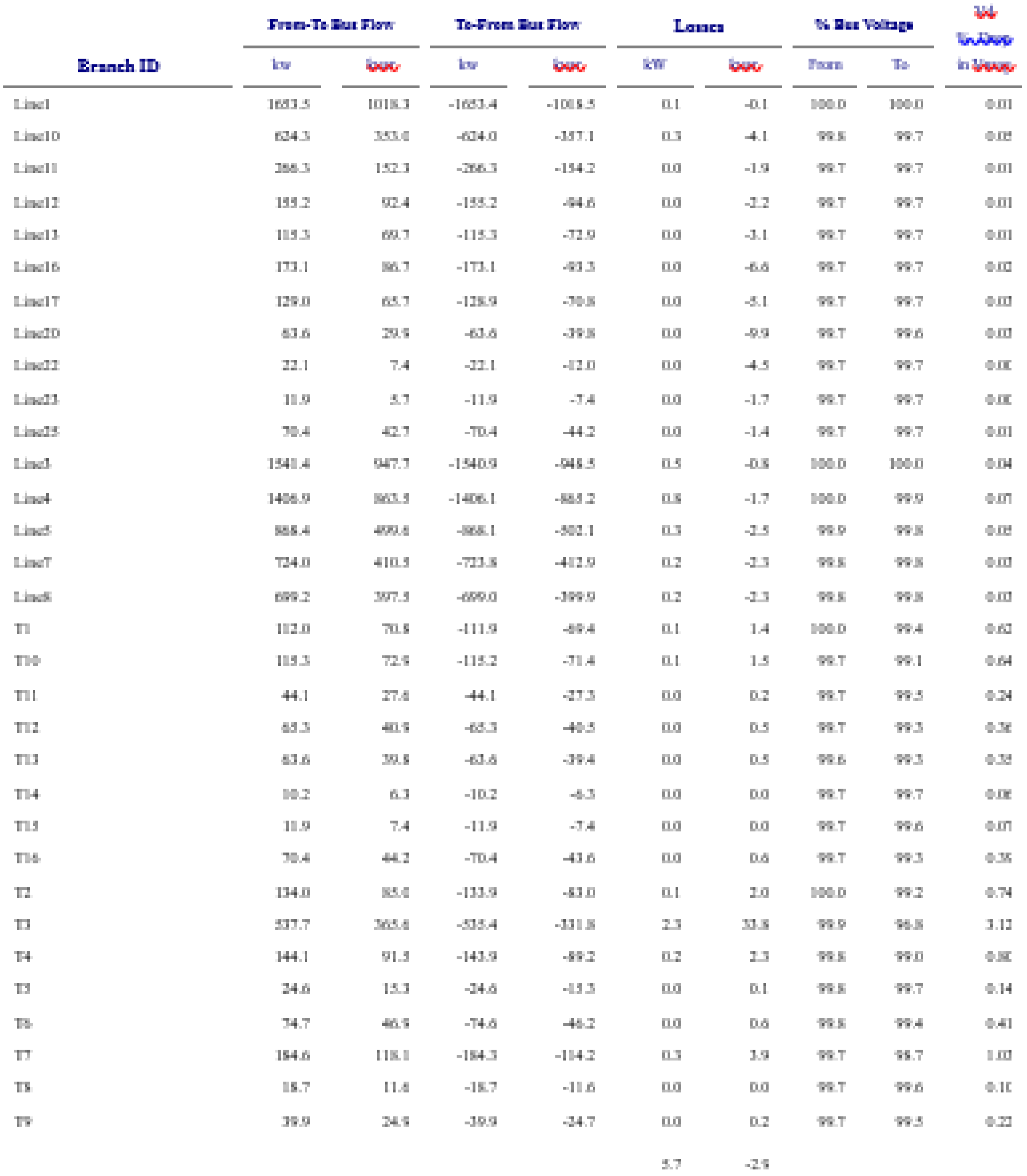


Figure 5.5 Harmonic distortion for buses (all buses)

The harmonic distortion before EVs integration were in normal operating range but when they are integrated, the harmonics increases to the level that they exceed the maximum allowable limits. Additional costs incur to address the harmonic distortion filters.

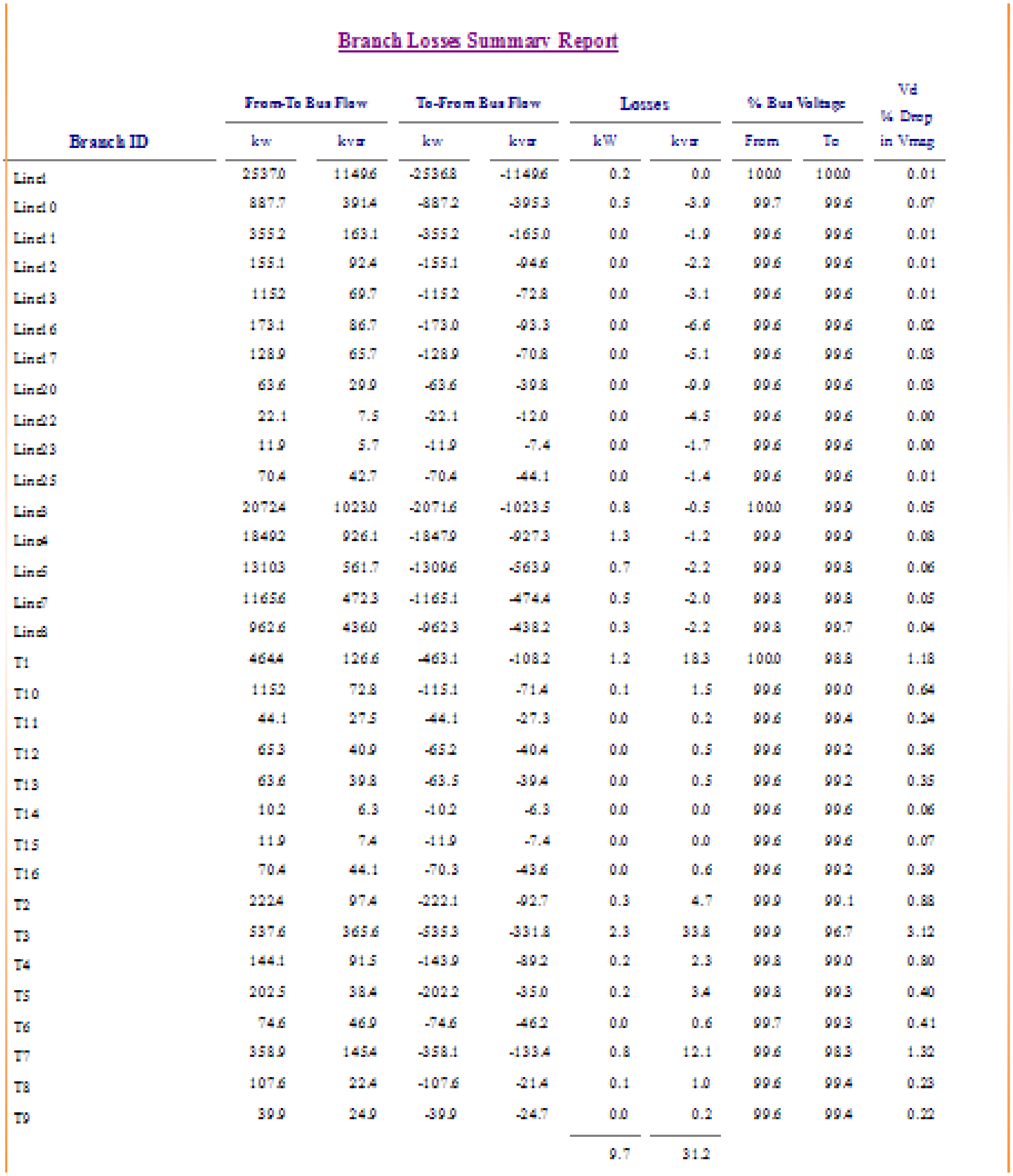
5.4 POWER LOSS

Table 5.6 Power loss before EV integration



Branch ID	From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop in Vmag
	kW	kvar	kW	kvar	kW	kvar	From	To	
Line1	1653.5	1018.3	-1653.4	-1018.5	0.1	-0.1	100.0	100.0	0.01
Line10	624.3	353.0	-624.0	-357.1	0.3	-4.1	99.8	99.7	0.05
Line11	266.3	152.3	-266.3	-154.2	0.0	-1.9	99.7	99.7	0.01
Line12	155.2	92.4	-155.2	-94.6	0.0	-2.2	99.7	99.7	0.01
Line13	115.3	69.7	-115.3	-72.9	0.0	-3.1	99.7	99.7	0.01
Line16	173.1	86.7	-173.1	-93.3	0.0	-6.6	99.7	99.7	0.02
Line17	129.0	65.7	-128.9	-70.8	0.0	-5.1	99.7	99.7	0.03
Line20	63.6	29.9	-63.6	-39.8	0.0	-9.9	99.7	99.6	0.03
Line22	22.1	7.4	-22.1	-12.0	0.0	-4.5	99.7	99.7	0.0
Line23	11.9	5.7	-11.9	-7.4	0.0	-1.7	99.7	99.7	0.0
Line25	70.4	42.7	-70.4	-44.2	0.0	-1.4	99.7	99.7	0.01
Line3	1541.4	947.7	-1540.9	-948.5	0.5	-0.8	100.0	100.0	0.04
Line4	1406.9	863.5	-1406.1	-865.2	0.8	-1.7	100.0	99.9	0.07
Line5	868.4	499.6	-868.1	-502.1	0.3	-2.5	99.9	99.8	0.05
Line7	724.0	410.5	-723.8	-412.9	0.2	-2.3	99.8	99.8	0.03
Line8	699.2	397.5	-699.0	-399.9	0.2	-2.3	99.8	99.8	0.03
T1	112.0	70.8	-111.9	-69.4	0.1	1.4	100.0	99.4	0.62
T10	115.3	72.9	-115.2	-71.4	0.1	1.5	99.7	99.1	0.64
T11	44.1	27.6	-44.1	-27.3	0.0	0.2	99.7	99.5	0.24
T12	65.3	40.9	-65.3	-40.5	0.0	0.5	99.7	99.3	0.38
T13	63.6	39.8	-63.6	-39.4	0.0	0.5	99.6	99.3	0.35
T14	10.2	6.3	-10.2	-6.3	0.0	0.0	99.7	99.7	0.08
T15	11.9	7.4	-11.9	-7.4	0.0	0.0	99.7	99.6	0.07
T16	70.4	44.2	-70.4	-43.6	0.0	0.6	99.7	99.3	0.35
T2	134.0	85.0	-133.9	-83.0	0.1	2.0	100.0	99.2	0.74
T3	537.7	365.6	-535.4	-331.8	2.3	33.8	99.9	96.8	3.12
T4	144.1	91.5	-143.9	-89.2	0.2	2.3	99.8	99.0	0.8
T5	24.6	15.3	-24.6	-15.3	0.0	0.1	99.8	99.7	0.14
T6	74.7	46.9	-74.6	-46.2	0.0	0.6	99.8	99.4	0.41
T7	184.6	118.1	-184.3	-114.2	0.3	3.9	99.7	98.7	1.03
T8	18.7	11.6	-18.7	-11.6	0.0	0.0	99.7	99.6	0.1
T9	39.9	24.9	-39.9	-24.7	0.0	0.2	99.7	99.5	0.22
					5.7	-2.9			

Table 5.7 Power loss after EV integration



Branch Losses Summary Report

Branch ID	From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop in Vmag
	kw	kvar	kw	kvar	kW	kvar	From	To	
Line1	2537.0	1149.6	-2536.8	-1149.6	0.2	0.0	100.0	100.0	0.01
Line10	887.7	391.4	-887.2	-395.3	0.5	-3.9	99.7	99.6	0.07
Line11	355.2	163.1	-355.2	-165.0	0.0	-1.9	99.6	99.6	0.01
Line12	155.1	92.4	-155.1	-94.6	0.0	-2.2	99.6	99.6	0.01
Line13	115.2	69.7	-115.2	-72.8	0.0	-3.1	99.6	99.6	0.01
Line16	173.1	86.7	-173.0	-93.3	0.0	-6.6	99.6	99.6	0.02
Line17	128.9	65.7	-128.9	-70.8	0.0	-5.1	99.6	99.6	0.03
Line20	63.6	29.9	-63.6	-39.8	0.0	-9.9	99.6	99.6	0.03
Line22	22.1	7.5	-22.1	-12.0	0.0	-4.5	99.6	99.6	0.00
Line23	11.9	5.7	-11.9	-7.4	0.0	-1.7	99.6	99.6	0.00
Line25	70.4	42.7	-70.4	-44.1	0.0	-1.4	99.6	99.6	0.01
Line3	2072.4	1023.0	-2071.6	-1023.5	0.8	-0.5	100.0	99.9	0.05
Line4	1849.2	926.1	-1847.9	-927.3	1.3	-1.2	99.9	99.9	0.08
Line5	1310.3	561.7	-1309.6	-563.9	0.7	-2.2	99.9	99.8	0.06
Line7	1165.6	472.3	-1165.1	-474.4	0.5	-2.0	99.8	99.8	0.05
Line8	962.6	436.0	-962.3	-438.2	0.3	-2.2	99.8	99.7	0.04
T1	464.4	126.6	-463.1	-108.2	1.2	18.3	100.0	98.8	1.18
T10	115.2	72.8	-115.1	-71.4	0.1	1.5	99.6	99.0	0.64
T11	44.1	27.5	-44.1	-27.3	0.0	0.2	99.6	99.4	0.24
T12	65.3	40.9	-65.2	-40.4	0.0	0.5	99.6	99.2	0.36
T13	63.6	39.8	-63.5	-39.4	0.0	0.5	99.6	99.2	0.35
T14	10.2	6.3	-10.2	-6.3	0.0	0.0	99.6	99.6	0.06
T15	11.9	7.4	-11.9	-7.4	0.0	0.0	99.6	99.6	0.07
T16	70.4	44.1	-70.3	-43.6	0.0	0.6	99.6	99.2	0.39
T2	222.4	97.4	-222.1	-92.7	0.3	4.7	99.9	99.1	0.88
T3	537.6	365.6	-535.3	-331.8	2.3	33.8	99.9	96.7	3.12
T4	144.1	91.5	-143.9	-89.2	0.2	2.3	99.8	99.0	0.80
T5	202.5	38.4	-202.2	-35.0	0.2	3.4	99.8	99.3	0.40
T6	74.6	46.9	-74.6	-46.2	0.0	0.6	99.7	99.3	0.41
T7	358.9	145.4	-358.1	-133.4	0.8	12.1	99.6	98.3	1.32
T8	107.6	22.4	-107.6	-21.4	0.1	1.0	99.6	99.4	0.23
T9	39.9	24.9	-39.9	-24.7	0.0	0.2	99.6	99.4	0.22
					9.7	31.2			

The power loss consists of two components active and reactive power losses. The active power loss shifts from 5.7kW to 9.7kW and reactive power from -2.5kVAR to 31.2kVAR. This shows a rise of 4kW and 33.7kVAR active and reactive power loss respectively when EVs are integrated into the network.

5.5 LOCATION OF CHARGING STATIONS

The charging stations are located by gradually loading each and every bus and determine whether the power quality is within acceptable limits.

Table 5.8 EV charging stations location

Bus 19	Bus 20	Bus 21	Bus 22	Bus 23	Bus 24	Bus 25	Bus 26	Bus 27	Bus 28	Bus 29	Bus 30	Bus 31	Bus 32	Bus 33	Bus 34
4	1	0	0	2	0	2	1	0	0	0	0	0	0	0	0

Taking into account the voltage stability, power loss, transformer loading and harmonic distortion, EVs are located on the load point (buses) as shown above for the sake of keeping the power quality within safe limits.

5.6 DETERMINE OF APPROPRIATE CHARGING HOURS FOR ELECTRIC VEHICLES

The data collected to the site shows that the tariff for industrial customers depends on two factors to take into account the energy consumption as well as the maximum demand offered to the grid by the industry. The maximum demand is charged differently on the basis of connection period in three categories viz off peak, shoulder and peak period. The least chargeable period is during off peak period and the cost rises gradually from it to the peak period. Since EVs substation operates as industrial customers, the substation owners have to schedule the charging period so that most of EVs are connected from 11:00 PM to 07:59 AM to lessen the cost using EVs affordable.

6. CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

The effect of EVs integration in distribution network is investigated though voltage sensitivity, power loss, system loadability and harmonic distortion studies. Simulation of the results were conducted on a 34 buses distribution system via etap software. The results show an immediate impact of harmonic distortion and bus loadability due to increased load on the system and charging cycles of EV batteries.

The voltage stability is less affected by EV integration since reactive power changes in not significantly high to the level of causing significant voltage sensitivity deviation and the power loss increases as number of EVs on the network increases. These results helped the author to locate EVs on specific buses in order to minimizes their impact on power quality of the system but keep enjoy their positive traits to the environment.

EVs require electric supply such as EV charging station. A complete design of the power supply has been performed taking into account the grid and battery specifications available at local market. The electric supply design is made possible through matlab software and simulation of the results is shown within this work.

Finally, appropriate charging period has been identified from power profile and utility tariff analysis in order to minimize the cost of electricity incurred since penalties are charged for industrial loads connected during off peak period.

6.2 RECOMMENDATIONS

The results shown indicates less number of EV integrated in comparison to electric vehicle demand and industry yearly target which sits at 1000 EV assembled per year. This requires power utility to respond to this proposed load growth by considering the aforementioned loads in generation, transmission and distribution planning.

Furthermore, EVs charging stations produces current and voltage harmonics which affects electrical equipment, nearby loads and neighboring telecommunication lines. Harmonic filtering devices such as RHSs, SCs and hybrid devices built on RHSs and SCs are required in distribution network to cope with the effects produced by harmonics. This should reduce the size of transformers and both transmission and distribution cables.

Finally, the author hypotheses that EVs integration affect the power system reliability as well as EV charging service reliability. A complete research on impact of EVs integration on systems reliability is recommended to address the issues that may arise during this project implementation.

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