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ASSESSING REQUIRED UPGRADES ON ELECTRICITY DISTRIBUTION NETWORK IN TORORO TO ADOPT E-MOBILITY CHARGING INFRASTRUCTURE
Case study Town Ring 11Kv feeder

SUPERVISED BY;

Prof. RICHARD OKOU

A FINAL YEAR PROJECT PROPOSAL TO BUSITEMA UNIVERSITY IN PARTIAL FULFILLMENT OF REQUIREMENTS FOR THE AWARD OF THE DEGREE OF BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING.

DECLARATION

We do declare this project report is our original work. All information presented is, to the best of our knowledge, accurate and was completed while pursuing our degree at Busitema University. This report does not contain any material previously published or written by a third party, except the citations and references we have provided.

OPIO PAUL BU/UP/2022/1245

Signature: ....

Date: 29th June 2026

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Signature.......................................

Date. 29th June 2026

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APPROVAL

This report has been submitted for examination with the approval of the project supervisor.

Prof. RICHARD OKOU

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Signature: ....

Date: 27th June 2026

ABSTRACT

Uganda's growing adoption of electric vehicles (EVs), driven by the National E-Mobility Strategy, presents both opportunities and challenges for the existing electricity distribution infrastructure. This study assesses the required upgrades on the electricity distribution network in Tororo to support e-mobility charging infrastructure, using the Town Ring 11 kV feeder supplied from Tororo Rock Substation as a case study.

Primary data was collected through field visits, interviews with electric motorcycle operators from Spiro and Gogo, and site visits to battery swapping stations. Secondary data was obtained from the Uganda E-Mobility Report and MEMD publications. Energy demand was estimated using the formula $E = N \times S \times Es$, and EV growth was projected from a baseline of 300 electric motorcycles in 2025 to 4,000 by 2030, with electric cars growing from 0 to 50 over the same period.

Network simulation was carried out under three scenarios: baseline with no EVs, 10% EV penetration, and 30% EV penetration. Results show that the feeder's peak demand of 1,820 kW already exceeds its thermal limit of 1,800 kW before any EV load is added. At 30% EV penetration, five out of eleven transformers enter overload conditions. The integration of EV charging infrastructure significantly reshapes the load profile, with the evening peak increasing from 1,820 kW to a projected total of 6,010 kW by 2030.

The study recommends upgrading overloaded transformers, increasing cable capacity, and deploying smart charging strategies to shift EV demand to off-peak hours, ensuring reliable and stable grid operation as e-mobility adoption accelerates in Tororo.

List of Acronym

Acronym	Meaning
AC	Alternating Current
BEV	Battery Electric Vehicle
BSS	Battery Swapping Station
DC	Direct Current
E2W	Electric Two-Wheeler
ERA	Electricity Regulatory Authority
EV	Electric Vehicle
HEV	Hybrid Electric Vehicle
HV	High Voltage
kW	Kilowatt
kWh	Kilowatt-Hour
LDV	Light Duty Vehicle
TRM	Transformer
MEMD	Ministry of Energy and Mineral Development
MW	Megawatt
MV	Medium Voltage
PHEV	Plug-in Hybrid Electric Vehicle
SDG	Sustainable Development Goal
THD	Total Harmonic Distortion
UEB	Uganda Electricity Board
UEDCL	Uganda Electricity Distribution Company Limited
UEGCL	Uganda Electricity Generation Company Limited

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CHAPTER 1
INTRODUCTION.

This chapter gives a brief background on this research is and where previous work that is related to this project is outlined. The problem statement and justification are presented.

1.1 Background

Uganda is well placed to emerge as a leading hub for electric mobility within East Africa. This advantage is supported by the country's substantial renewable energy generation largely from hydropower along with a favourable policy framework guided by the National E-Mobility Strategy. In line with this policy direction, the Government of Uganda, under the leadership of Yoweri Kaguta Museveni, has taken deliberate steps toward developing a strong, competitive, and sustainable mobility value chain. These efforts emphasize collaboration among government institutions, the private sector, academia, and development partners. In national addresses delivered on 20th and 27th July and 5th August 2022, the President underscored that a sustainable solution to Uganda's fuel challenges lies in transitioning from petrol-based transport to electric vehicles including cars, buses, motorcycles, trains and further indicated that the country should aim to achieve full electrification of transport within the next two decades.

National e-mobility assessments further highlight ambitious adoption targets and rapid projected growth. These include achieving 100% electrification of public transport and motorcycles by 2030, reaching 30% electric vehicle sales by 2030, and deploying at least 15,000 electric buses by 2040. In the near term, projections indicate approximately 74,000 electric motorcycles could be in operation by 2026, with revised scenarios estimating up to 450,000 cumulative electric motorcycles by 2030. Given that motorcycles currently account for about 65% of Uganda's public vehicle fleet, this transition represents a significant shift in national electricity demand patterns**.** In addition, Uganda is increasingly becoming a regional centre for the production and distribution of electric vehicle (EV) technologies. The national strategy sets ambitious goals for expanding EV adoption across multiple transport categories, including motorcycles, passenger vehicles, minibuses, and heavy-duty commercial vehicles.

The electricity distribution network in Tororo is managed by Uganda Electricity Distribution Company Limited (UEDCL), which was established on April 1, 2001, following the restructuring of the former Uganda Electricity Board. UEDCL owns all grid-connected distribution assets operating at voltage levels of 33 kV and below. Although a significant portion of these assets has historically been managed by concessionaires, UEDCL currently operates key urban, peri-urban, and regional distribution systems and delivers most of the grid electricity. The company also oversees several rural service areas, where smaller cooperatives lease and manage infrastructure originally developed under the Rural Electrification Agency.

This technical study focuses specifically on the **11 kV and low-voltage (LV) distribution network**, with particular emphasis on the **Town Ring 11 kV feeder originating from the Tororo Rock Substation** and operated by UEDCL. The increasing uptake of EVs is anticipated to significantly alter electricity demand patterns across the country. Estimation of EV charging demand is based on a combination of real operational data from battery swapping stations (BSS) for electric motorcycles and simulation-based approaches for other vehicle types such as cars, three-wheelers, minibuses, and buses. These methods incorporate critical parameters including battery size, charger efficiency, charging locations, and user behaviour, allowing for the generation of realistic daily load demand profiles. In cases where detailed vehicle distribution data is unavailable, the spatial distribution of fuel stations is used as an approximate indicator of EV penetration and associated electricity demand.

While the adoption of EVs offers substantial benefits such as reduced greenhouse gas emissions, improved air quality, and decreased reliance on fossil fuels it also introduces technical challenges to the power system. High levels of EV penetration can result in increased peak demand, voltage fluctuations, network congestion, and higher system losses, particularly within **11 kV and LV distribution networks**. Regional urban centres such as Tororo are increasingly exposed to these challenges as EV adoption expands, with potential impacts including transformer overloading and voltage drops along feeders such as the Town Ring network.

To address these challenges, smart charging techniques are proposed to shift EV charging to off-peak periods, thereby easing pressure on the grid. Furthermore, planned infrastructure developments, such as the deployment of new high-voltage/medium-voltage (HV/MV) substations by 2030, are expected to mitigate many of the identified constraints. Nevertheless, without adequate planning and timely investment, rapid EV adoption may negatively affect grid stability and increase operational costs. This underscores the importance of integrated planning between the energy and transport sectors.

This project therefore delivers a quantitative and evidence-based evaluation of the upgrades required for the **Town Ring 11 kV feeder in Tororo** to reliably accommodate EV charging infrastructure.

1.2 PROBLEM STATEMENT

Though Uganda has adequate electricity generation capacity of 2048 MW, the distribution network is not designed to handle the high and concentrated loads from electric vehicle (EV) charging. Charging demands ranging from 1.4 kW (E2W) to 50 kW (fast chargers) can create significant stress on 11 kV and low-voltage feeders, especially when many users charge simultaneously.

As EV adoption increases, uncontrolled charging particularly during peak periods can overload transformers and feeders, causing voltage drops, increased power losses, and reduced system efficiency. This threatens grid reliability and the quality of power supply.

Without proper evaluation and timely upgrades, the network may experience instability and unreliable EV charging services, which could slow down the transition to e-mobility.

Therefore, assessing the impact of EV charging and determining the required distribution network upgrades is essential to:

- Ensure reliable and stable grid operation
- Prevent equipment overloading and failures
- Maintain acceptable voltage levels and power quality
- Support sustainable and large-scale EV adoption

1.3 JUSTIFICATION OF THE STUDY

A reliable and highly efficient electricity distribution network is a critical infrastructure requirement that directly impacts EVs charging Infrastructure development, the consequences of network inefficiencies extend far beyond immediate service disruptions. This study is highly significant because it provides proactive planning and quantitative modeling to de-risk future infrastructure investments, beginning with preventing grid failure by identifying potential overload and voltage issues to avoid power outages and equipment damage from unmanaged EV load growth.

Furthermore, the results will inform policy and investment by providing utility and regulatory bodies with vital insights on the location, type, and capacity of charging stations, ensuring a structured approach to the sector's expansion in Kampala.

Crucially, it will optimize costs by determining the minimum necessary upgrades, including smart charging, thereby preventing unnecessary, costly investments in traditional grid infrastructure.

Finally, the work will promote sustainability by facilitating a reliable charging network, which is essential for increasing the uptake of EVs, directly contributing to the reduction of greenhouse gas emissions and improved air quality Tororo.

1.4 MAIN OBJECTIVE

To assess the impact of e-mobility adoption on Tororo distribution network over a five-year forecast period and model the reliable efficient and cost-effective distribution network.

1.5 SPECIFIC OBJECTIVES

1. To quantify the current baseline and projected future electricity demand of electric vehicles.
2. To module, simulate practical network upgrade measures on Town Ring 11kv feeder to support reliable EV charging deployment.
3. To determine the new load profile due to the E-mobility charging infrastructure on the network

1.6 Research Questions

- What is the current baseline electricity demand of electric vehicles, and how is EV electricity demand projected to grow on the Town Ring 11 kV feeder over the next five years?

- How does the integration of EV charging infrastructure affect the operational performance of the Town Ring 11 kV feeder in terms of voltage profile, transformer loading, feeder loading, and network losses?
- What practical, reliable, and cost-effective network upgrade measures are required to accommodate future EV charging demand on the Town Ring 11 kV feeder?
- How does the adoption of e-mobility charging infrastructure reshape the 24-hour load profile of the Town Ring 11 kV feeder under different EV penetration scenarios?

1.7 SCOPE OF THE STUDY

The study is limited to the low voltage (LV) and medium voltage (MV) distribution network within Tororo town, focusing on one specific case study feeder which is the town ring 11kV Feeder, supplied from the Tororo rock Substation. The study addresses the electrical grid's capacity and reliability only and does not include financial modeling for EV charging business operations or analysis of the upstream transmission system beyond the 33 kV grid supply point at Tororo main substation.

CHAPTER 2

LITERATURE REVIEW.

This chapter gives a brief introduction to Uganda’s Electricity sector and Electricity Distribution Network, E-mobility landscape in Uganda and the related technical work.

2.1 Distribution network and operations

Uganda’s electricity sub-sector operates under a liberalized structure following the enactment of the Electricity Act of 1999, which mandated the unbundling of the Uganda Electricity Board (UEB) into three distinct entities which include Uganda Electricity Generation Company Limited (UEGCL), Uganda Electricity Transmission Company Limited (UETCL), and Uganda Electricity Distribution Company Limited (UEDCL). The Ministry of Energy and Mineral Development (MEMD) provides policy direction, while the Electricity Regulatory Authority (ERA) sets operational standards, technical guidelines, and tariff frameworks for the sector

Uganda’s generation is predominantly hydropower, with the backbone transmission network running at 132kV and 66kV from Jinja to tororo. UEDCL owns and manages the distribution infrastructure at 33kV and below, encompassing 14,833 distribution transformers, 14,635 kilometers of medium voltage network, 22,405 kilometers of low voltage network, 178 metering sites, and 74 substations and switching stations. The company distributes electricity to customers operating between 33kV and 240V, and is responsible for the expansion, operation, maintenance, and upgrading of distribution infrastructure.

2.2 E-mobility landscape in Uganda.

The e-mobility landscape in Uganda is characterized by rapid growth in the two-wheeler (E2W) segment, supported by battery swapping networks and approximately 500 battery swap stations are currently operational across the country. A smaller but growing presence of AC fast chargers serves cars and minibuses.

Uganda’s EV fleet projections, as documented in the MEMD 2024 Terms of Reference for the Diagnostic Study on E-Mobility Market Development, indicate significant growth across all vehicle categories by 2030

This table presents the projected growth of Uganda’s vehicle fleet forecast across different categories between 2025 and 2030, highlighting the rapid increase in electric mobility adoption, particularly in the motorcycle segment

Vehicle Category	2025 Forecast	2030 Forecast	Growth (%)
Motorcycles (E2W)	98,684	1,516,835	+1,437%
Cars	488,784	659,940	+35%
Minibuses	36,663	40,648	+11%
Buses	28,492	31,589	+11%
Commercial Vehicles	154,364	218,683	+42%
Three-Wheelers	10,619	15,043	+42%
TOTAL	818,606	2,482,738	+203%

2.3 Related technical work

Review of related literature identifies a gap between national level EV policy studies and feeder level technical impact assessments. Existing work has assessed the e-mobility market at a macro level covering fleet segmentation, technology types (BEV, HEV, and PHEV), charging infrastructure mapping, and the policy and regulatory environment but quantitative load flow analysis at the feeder level for Tororo specific 11kV radial networks has not been published. This project directly fills that gap by providing the first known simulation-based assessment of the town ring under structured EV penetration scenarios.

International literature confirms that radial 11kV urban feeders like Tororo's are highly susceptible to end-of-feeder voltage drops when EV fast charger clusters are introduced at commercial nodes and that Total Harmonic Distortion (THD) can exceed regulatory limits with as few as three Level 3 DC chargers on a single feeder section (IEEE Std 1547-2018). Smart charging with demand response coordination has been shown to defer up to 60% of required capital infrastructure upgrades in comparable Sub-Saharan African grid contexts.

CHAPTER 3

METHODOLOGY

The methodology adopts a three-phase approach consisting of data collection, network modelling, and analysis to evaluate the effects of e-mobility charging infrastructure on the distribution network.

3.1 To quantify the current baseline and projected future electricity demand of electric vehicles

3.1.1 Distribution Network Data Collection

To establish the baseline operating condition of the Town Ring 11 kV feeder, operational and technical data were obtained from UEDCL records and field observations. The collected data provides a comprehensive representation of the feeder's loading characteristics, energy consumption patterns, transformer capacities, and customer distribution. These parameters form the basis for assessing the impact of e-mobility charging infrastructure on the distribution network and for subsequent network modelling and simulation. The key distribution network data collected for this study are summarized in Table 1.

Table 1:Summary of Distribution Network Data Collected

Parameters	Unit	Description
Peak load	1.82MW	Maximum demand recorded on the feeder
Monthly Energy consuption	1.81MW	Total monthly energy supplied through the feeder
Number of transformers	150	Total transformers connected to the feeder
Customer Categories	-	Residential, Commercial, Industrial and Institutional customers

3.1.2 Transformer Ratings:

The feeder comprises 46 transformers with ratings of which only 11transformers were taken for the case study. The distribution of transformer ratings is summarized.

Table 2:The distribution of transformer ratings

Transformer Rating (kVA)	Number of transformers
500	2
200	5
100	3
50	1

3.1.3 Conductor Parameters

The feeder uses Aluminium-Conductor Steel Reinforced

(ACSR) 100 mm2 conductors. The conductor parameters such as current rating reactance, and sequence resistance are provided in table 3

Table 3:The conductor parameters

type	Current rating(A)	R_+ (Ω/km	R_0 (Ω/km)	X_+ (Ω/km)	X_0 (Ω/km)	G_+ (Ω/km)	G_0 (s/km)
ACSR 100mm^2	360	0.273	0.423	0.341	1.701	1.431	0.138

3.1.4 EV Data

To estimate the future electricity demand associated with e-mobility adoption on the Town Ring 11 kV feeder, national electric vehicle statistics, growth projections, and charging characteristics were obtained from the National E-Mobility Strategy (2023) and the E-Mobility Market Diagnostic Assessment (2024). These data provide the basis for forecasting EV penetration levels and calculating the corresponding charging demand expected on the distribution network.

Table 4:EV Population and National E-Mobility Projections

Type	Scenario	Value
Motorcycles(E2W)	Baseline (2026)	300
	Forecast (2030)	4000
Electric Vehicles	Baseline (2026)	0
	Forecast (2030)	50

The values presented in Table 5 represent the average charging characteristics obtained from field surveys, stakeholder interviews, and charging infrastructure assessments. These parameters were subsequently used in estimating EV electricity demand and developing future load profiles for the Town Ring 11 kV feeder.

Table 5:The average charging characteristics of Evs

EV category	Battery Capacity (kWh)	Charger Rating (kW)	Average Daily Distance (km/day)	Charging Frequency (charges/day)	Average Charging Duration (hrs.)
Motorcycle (E2W)	2.5	1.4	80	2	2
Electric Car	50	7	120	1	7

3.1.5 Baseline EV energy demand

Based on field data and observations, the total electric motorcycle fleet in Tororo stands at **300 units**. Spiro accounts for **80% (240 units)** of this fleet, while other players account for the remaining **20% (60 units)**. Currently, there are **no electric cars** registered in Tororo district.

3.2.1 Electric Motorcycles

Energy demand was calculated using the formula:

$$E = N \times S \times E_S$$

Where; N = number of active motorcycles,

S = swaps per day (2),

Es = energy per swap (2.5 kWh).

Applying the formula for the current fleet of 300 active motorcycles:

$$E = 300 \times 2 \times 2.5$$

$$= 1{,}500 \text{ kWh/day}$$

3.1.6 Electric Cars

Energy demand for electric cars is computed based on usage patterns. Private cars are assumed to charge once per day, public cars charge twice per day, and LDVs have higher consumption due to commercial use. The energy per charge session is estimated at 15 kWh for private and public cars, and 25 kWh for LDVs. As there are currently no electric cars deployed in Tororo, the baseline car energy demand is 0 kWh/day.

3.1.7 Infrastructure Capacity Assessment

Swapping Stations

The capacity per station is calculated as:

$$C_s = N_b \times E_b$$

Where; C_s= capacity per station

N_b = Number of batteries

E_b= Energy per battery

$= 30 \times 2.5$

$= 75$ kWh/day

Charging Station

A charging station with a power rating of 50 kW, operating for 10 hours per day, delivers a total daily energy capacity of 500 kWh. This is expressed as:

Daily Energy (kWh) = Power (kW) × Operating Hours (h)

Daily Energy = 50 kW × 10 h = **500 kWh/day**

This means that within a single day, one charging station can supply a cumulative total of 500 kWh of electrical energy to all electric vehicles served at that station, provided it operates continuously for 10 hours.

The total daily energy demand of an electric car depends on its category, the energy required per charge session, and the number of charging sessions undertaken per day. This is expressed as:

Daily Energy per Car (kWh) = Energy per Session (kWh) × Number of Sessions per Day

- **Private car:** 15 kWh × 1 session = **15 kWh/day**
- **Public car:** 15 kWh × 2 sessions = **30 kWh/day**
- **LDV:** 25 kWh × 1 session = **25 kWh/day.**

3.1.8 EV Growth Forecasting Approach

The projection of electric vehicle (EV) adoption within Tororo was developed using a combination of demographic trends, field survey findings, industry observations, and national e-mobility projections to provide a realistic basis for forecasting future charging demand.

Population statistics from the recently concluded National Population and Housing Census (NPHC) indicate continued population growth and increasing urbanization in Tororo Municipality and its surrounding areas. This growth is expected to drive higher demand for mobility services, particularly commercial motorcycle transport, which remains the dominant mode of urban transport in the district. As population density, economic activity, and transport demand increase, the uptake of electric mobility solutions is expected to follow a similar trend.

Field interviews conducted with operators of electric motorcycles, including Spiro and GOGO riders, indicated that most motorcycles perform approximately two battery swaps per day, reflecting high daily utilization rates. Additional consultations with company representatives and visits to battery swapping stations revealed ongoing investments in fleet expansion, battery inventory, and charging infrastructure. The battery-swapping model significantly reduces charging downtime and improves operational efficiency, making electric motorcycles increasingly attractive to riders.

National projections contained in the National E-Mobility Strategy and the Uganda E-Mobility Market Diagnostic Assessment identify electric motorcycles as the fastest-growing EV segment due to their affordability, lower operating costs, and suitability for Uganda's transport sector. Government support for e-mobility, increasing private sector investment, and the gradual expansion of charging and battery-swapping infrastructure further support accelerated EV adoption.

Considering the projected population growth in Tororo, the increasing demand for urban mobility services, observed industry expansion trends, and national e-mobility targets, a progressive growth model was adopted for this study. The model assumes that electric motorcycle adoption will increase from an estimated baseline of 300 units to approximately 4,000 units by 2030, while electric cars are projected to increase from negligible current levels to about 50 units over the same period. The growth pattern is assumed to be non-linear, characterized by gradual initial adoption followed by accelerated growth as infrastructure availability, consumer awareness, and market confidence improve.

This forecasting approach provides a practical and evidence-based representation of future EV adoption in Tororo and forms the basis for estimating future charging demand and assessing the required upgrades to the Town Ring 11 kV distribution feeder.

Key Assumptions

- Electric motorcycles remain the dominant EV category within Tororo throughout the study period.
- Spiro is assumed to maintain approximately 80% market share of the electric motorcycle segment.
- Electric motorcycle adoption increases from 300 units at baseline to approximately 4,000 units by 2030.
- Electric car adoption increases from near-zero levels to approximately 50 vehicles by 2030.
- Growth follows a non-linear trend reflecting the typical technology adoption curve.
- Expansion of battery-swapping stations and charging infrastructure continues throughout the forecast period.
- Population growth, urbanization, and increasing transport demand positively influence EV adoption rates.

3.1.9 Infrastructure Forecasting

3.5.1. Swapping Stations

With each station having a capacity, C_s, the number of stations required is calculated from;

$$No\ of\ stations = E_m \div C_s$$

Where:

E_m is Total motorcycle energy

3.5.2. Charging Stations

With each charging station having capacity C_s, the number of stations required is calculated from;

$No\ of\ stations\ = E_c \div C_s$ where; $E_c\ is$ Total car energy.

3.1.10 Forecast EV energy demand

For E2W, energy formula applied:

E = N × S × Es where S = 2 swaps/day and Es = 2.5 kWh/swap

For electric cars, energy demand for charging stations is calculated from; $E = N \times S \times E_S$

Table 6: The forecast of EV energy demand

Year	E2W			Electric cars		
	Number	Energy (kWh/day)	Stations Needed	Number	Energy (kWh/day)	Stations Needed
2025	300	1500	8	0	0	0
2026	800	1500	10	5	101	1
2027	1500	4000	35	15	304	1
2028	2500	7500	40	25	506	3
2029	3500	12500	65	35	709	3
2030	4000	20000	80	50	1012	4

3.2 To model and simulate practical network upgrade measures on Town Ring 11 kV feeder to support reliable EV charging deployment

To evaluate the capability of the Town Ring 11 kV feeder to accommodate future e-mobility charging demand, the distribution network was modelled and simulated under different EV penetration scenarios using load flow analysis. The assessment considered the existing network configuration and investigated the impact of increasing EV charging loads on feeder loading, transformer loading, voltage profile, and network losses. Three operating scenarios were analysed, namely the baseline scenario (0% EV penetration), 10% EV penetration, and 30% EV penetration. The results obtained from each scenario were used to identify network constraints and evaluate practical upgrade measures required to ensure reliable and efficient EV charging deployment.

3.2.1 Baseline Network Performance (No EVs)

The baseline simulation was conducted with no EV load connected to the network, establishing the pre-EV condition of the Town Ring 11 kV feeder.

All buses-maintained a per-unit voltage of 0.99 p.u. across the network, except for bus 4 (BUS 4/0.415) which recorded 1.00 p.u. The 33 kV supply bus at Tororo Rock Substation maintained a nominal voltage of 1.00 p.u. The power transformer recorded a loading of 7.1%, indicating significant available headroom at the substation level. All distribution transformers were loaded at 60.5% of their rated capacity under natural load conditions, with the exception of TRM 200kVA(1) which recorded a loading of 24.1% and 100kVA(1) which recorded 12.1%, reflecting lower demand in those areas. The total active power supplied by the grid at baseline was 1.3 MW with a reactive power of 0.6 Mvar.

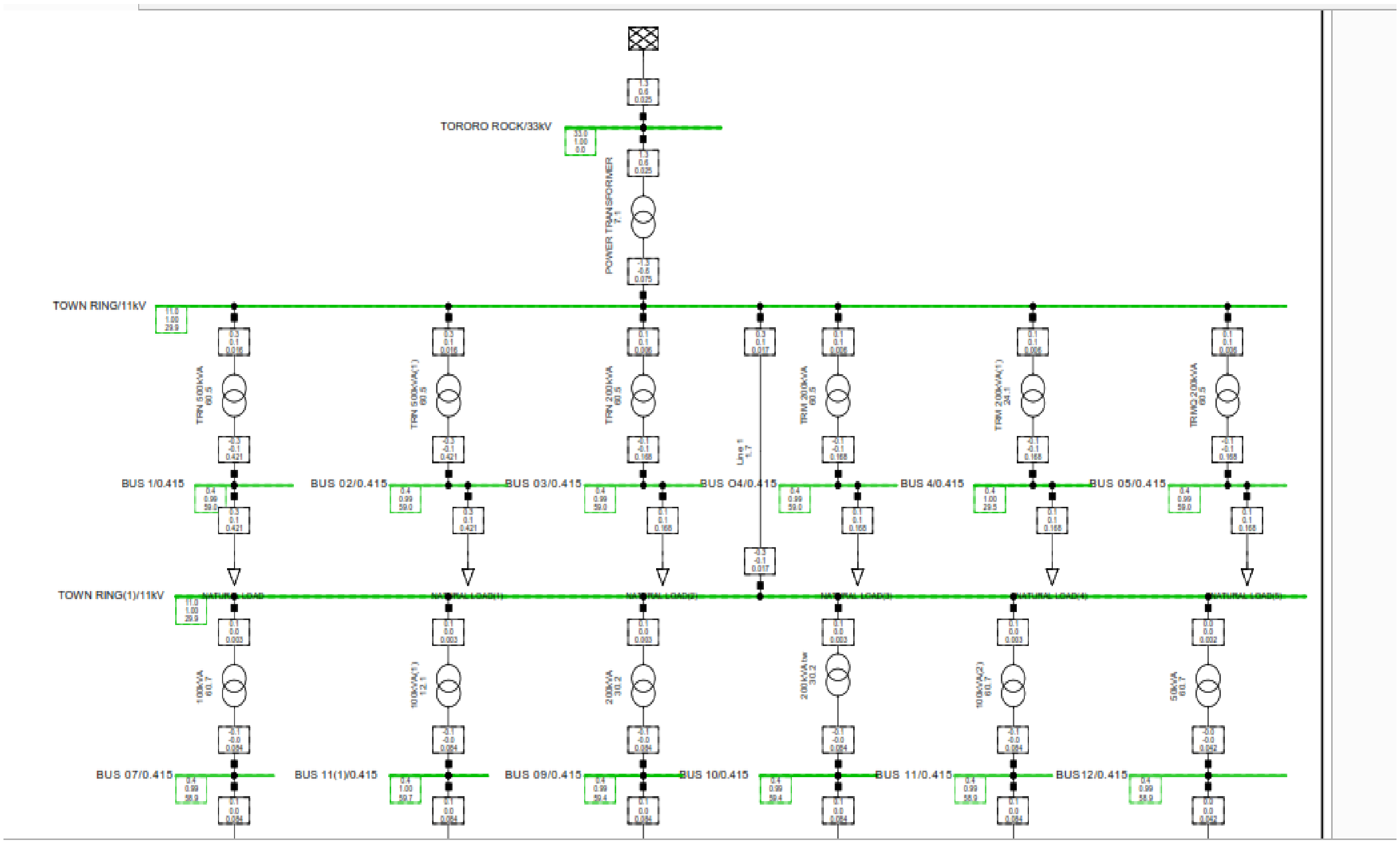

Figure 1:The baseline simulation scenario

3.2.2 Network Performance at 10% EV Penetration

At 10% EV penetration, an EV load of 89.55 kW was introduced and distributed across selected transformers. The results show a notable increase in transformer loading compared to the baseline. TRM 200kVA recorded a loading of 103.19%, entering overload conditions as a direct consequence of the combined natural load and additional EV charging demand. TRN 200kVA recorded a loading of 78.45%, placing it in the warning zone. TRN 500kVA recorded a loading of 69.59%, remaining within normal operating limits. The majority of remaining transformers maintained loadings between 12.05% and 60.66%.

Bus voltages across the network remained largely stable at 0.99 p.u., with bus 0.415(4) recording 1.00 p.u. and the 11 kV bus maintaining 1.00 p.u. The 11 kV line recorded a loading of 1.75%, and the power transformer loading increased slightly to 6.43% compared to the baseline. The total active power demand from the grid rose to 1.15 MW at the 11 kV level, with reactive power of 0.58 Mvar, reflecting the additional load introduced by EV charging.

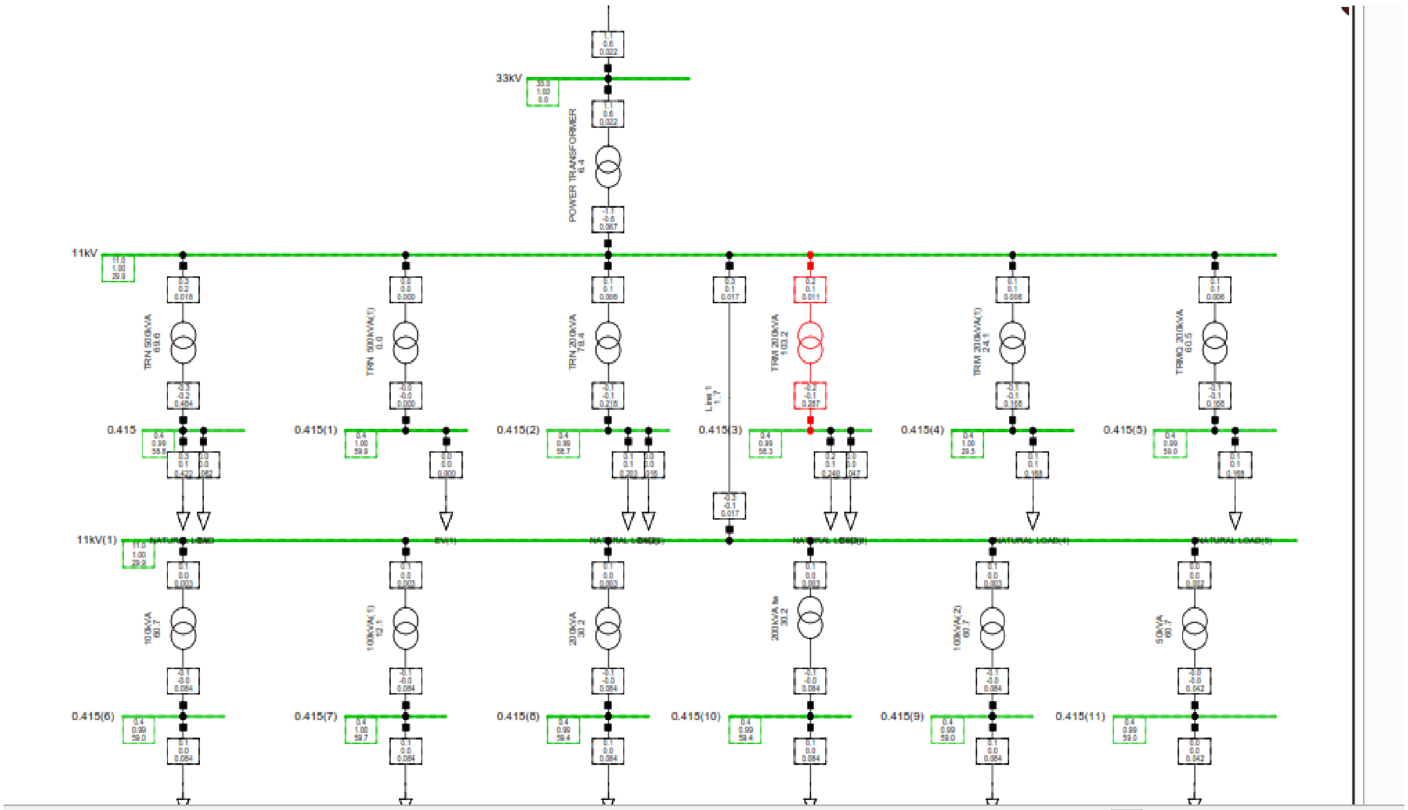

Figure 2:The 10% EV penetration scenario

3.2.3 Network Performance at 30% EV Penetration

At 30% EV penetration, EV load of 268.66 kW was distributed across all transformers. This scenario produced the most significant impact on the network. A total of five transformers entered overload conditions.

The 50kVA transformer recorded the highest overload at 293.6% of its rated capacity, posing a serious risk of thermal damage and reduced equipment lifespan. The 100kVA transformer recorded 184.5% loading, and 100kVA(2) recorded 100.4%. TRM 200kVA remained at 103.2% overload, consistent with the 10% penetration scenario, while TRN 200kVA recorded 78.5%, remaining in the warning zone.

Bus voltages showed a more pronounced decline at 30% penetration compared to baseline and 10% scenarios.

The 0.415(11) bus recorded the lowest voltage at 0.95 p.u., representing a drop of approximately 4% from nominal. The 0.415(6) bus recorded 0.97 p.u. and buses 0.415(3) and 0.415(9) recorded 0.98 p.u.

The 11 kV (1) bus voltage dropped to 0.99 p.u. from 1.00 p.u. at baseline, while the 33 kV supply bus remained stable at 1.00 p.u. The line loading on Line 1 increased from 1.75% at 10% penetration to 3.5% at 30% penetration.

The total active power drawn from the grid rose to 1.6 MW with reactive power of 0.8 Mvar, and the power transformer loading increased to 8.8%.

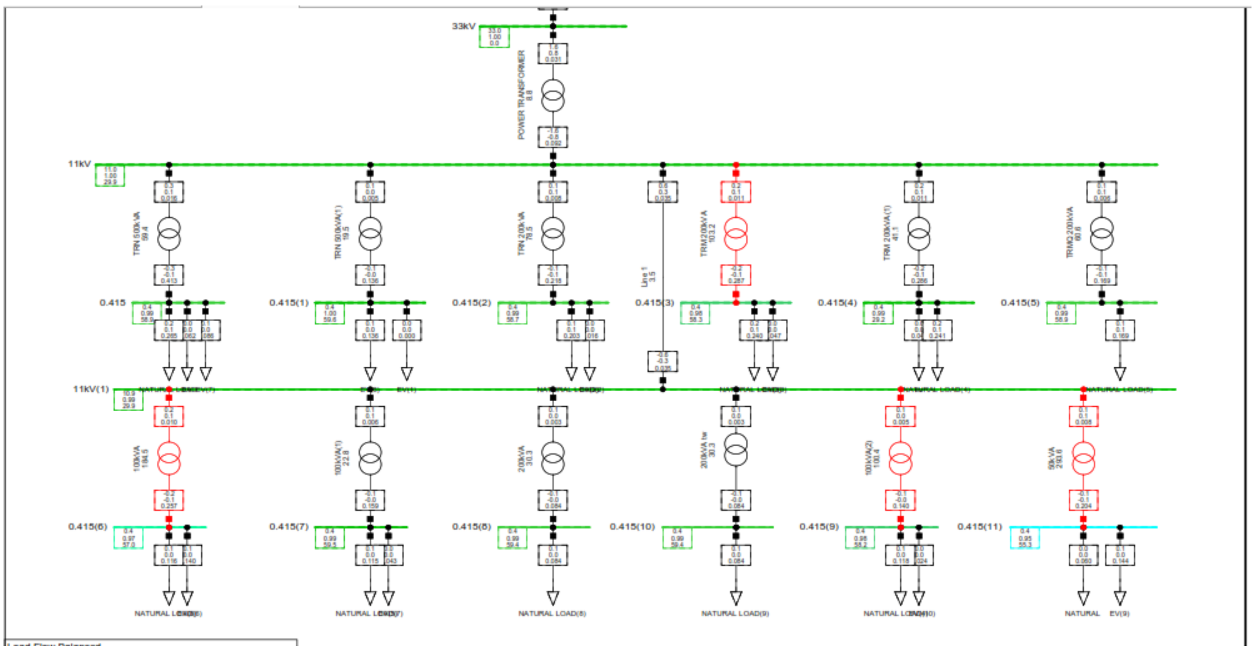

Figure 3: The 30% EV penetration scenario

3.2.4 Comparison of Key Parameters Across Scenarios

The table below summarizes the impact on key system parameters across the three simulated scenarios.

Parameter	Baseline (0%)	10% EV Penetration	30% EV Penetration
Grid active power (MW)	1.3	1.15	1.6
Power transformer loading (%)	7.1	6.43	8.8
Line 1 loading (%)	—	1.75	3.5
Minimum bus voltage (p.u.)	0.99	0.99	0.95
Transformers in overload	0	1	5
Supply bus voltage (p.u.)	1.00	1.00	1.00

Table 7: The impact on key system parameters across the three simulated scenarios.

3.3 To Determine the New Load Profile Due to the E-Mobility Charging Infrastructure on the Network

To evaluate the impact of e-mobility adoption on the Town Ring 11 kV feeder, a load profile analysis was conducted using 24-hour feeder loading data under both existing operating conditions and EV-integrated conditions. The baseline load profile was obtained from feeder metering records, while the EV-integrated load profiles were developed by incorporating the projected charging demand of electric motorcycles and electric cars under 10% and 30% EV penetration scenarios

Hour	BaselineLoad(kW)	10%EVpenetration(kW)	30%EVpenetration(kW)
00:00	655.2	655.2	655.2
01:00	618.8	618.8	618.8
02:00	600.6	600.6	600.6
03:00	582.4	582.4	582.4
04:00	618.8	618.8	618.8
05:00	673.4	673.4	673.4
06:00	1055.6	1066.7	1088.9
07:00	1274	1330.5	1443.5
08:00	1383.2	1439.7	1552.7
09:00	1437.8	1471.6	1539.2
10:00	1456	1478.2	1522.6
11:00	1419.6	1441.8	1486.2
12:00	1383.2	1405.4	1449.8
13:00	1346.8	1390.1	1476.7
14:00	1383.2	1426.5	1513.1
15:00	1419.6	1451.6	1515.6
16:00	1492.4	1513.5	1555.7
17:00	1583.4	1598.1	1627.5
18:00	1674.4	1728.2	1835.8
19:00	1820	1885.8	2017.4
20:00	1764.4	1819.2	1926.8
21:00	1619.8	1653.6	1721.2
22:00	1019.2	1025.4	1037.8
23:00	873.6	875.3	878.7

Table 8: Energy demand at different scenarios

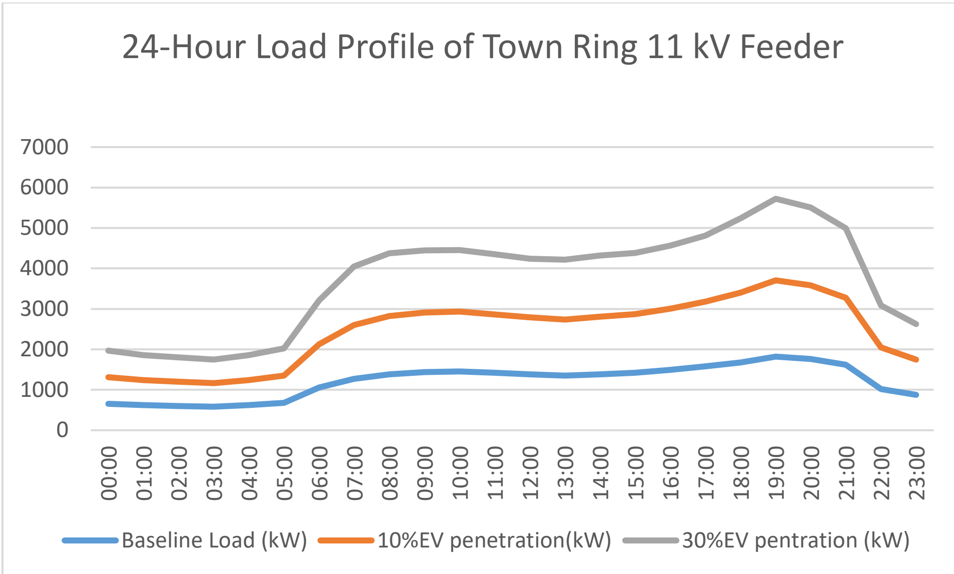

Figure 4: 24hour load profile at different scenarios

CHAPTER 4

RESULTS AND DISCUSSION

4.1.Impact of E-Mobility on Electricity Demand

The results indicate that the adoption of electric vehicles introduces additional demand on the Town Ring 11 kV feeder, resulting in a noticeable increase in feeder loading. Under the baseline scenario, the feeder operates within acceptable loading limits. However, under the 10% and 30% EV penetration scenarios, the load profile becomes increasingly elevated, particularly during morning and evening charging periods.

The 30% penetration scenario exhibits the highest peak demand due to the simultaneous charging of electric motorcycles and electric cars. This increase in demand demonstrates the growing stress placed on feeder infrastructure as EV adoption expands.

4.2.Impact on Daily Load Profile

Comparison of the baseline, 10% EV penetration, and 30% EV penetration load profiles shows that EV charging significantly reshapes the feeder demand curve.

Key observations include:

- Increased evening peak demand due to residential charging activities.
- Increased feeder utilization throughout the day.
- Higher daily energy consumption.
- Reduced load diversity as charging loads become concentrated during specific periods.

The load profile analysis indicates that unmanaged charging can intensify existing peak demand conditions and accelerate network congestion.

4.3.Voltage Profile Performance

Load flow simulations reveal that bus voltages decrease progressively with increasing EV penetration levels.

Under the baseline scenario, voltage levels remain within the acceptable distribution network operating range of 0.95–1.05 p.u.

At higher penetration levels, particularly under the 30% scenario, voltage drops become more pronounced towards the remote end of the feeder due to increased current flow and line impedance.

The results suggest that continued EV growth may require voltage support measures such as conductor reinforcement, transformer upgrades, or distributed charging infrastructure.

4.4. Transformer Loading Assessment

The simulation results indicate that transformer loading increases with EV adoption.

Transformers supplying commercial centres and densely populated urban areas experience the greatest loading increases due to the concentration of charging demand.

Although most transformers remain within operational limits under the 10% penetration scenario, some units approach their loading thresholds under the 30% penetration scenario, indicating the need for capacity reinforcement in future network planning.

4.5.Network Losses

The increase in feeder current resulting from EV charging causes a corresponding increase in technical losses.

Active power losses increase under both EV penetration scenarios, with the highest losses recorded under the 30% penetration scenario.

The increase in losses is primarily attributed to:

- Higher current flow through feeder conductors.
- Increased transformer loading.
- Extended charging durations during peak demand periods.

These findings highlight the importance of implementing efficient charging strategies and targeted network upgrades.

4.6.Power Quality Considerations

Electric vehicle chargers utilize power electronic converters, which are known sources of harmonic currents.

Although harmonic measurements were beyond the scope of this study, increased penetration of EV chargers is expected to contribute to:

- ❖ Current harmonic distortion.
- ❖ Voltage waveform distortion.
- ❖ Increased transformer heating.
- ❖ Reduced equipment lifespan.
- ❖ Additional network losses.

Concern exists under the 30% penetration scenario, where a large number of simultaneously operating chargers may increase Total Harmonic Distortion (THD) beyond recommended limits if mitigation measures are not implemented.

Utilities should therefore monitor harmonic levels as EV penetration increases.

4.7. Power System Stability

The integration of EV charging infrastructure introduces new dynamic loading characteristics to the distribution network.

Large-scale charging can result in:

- Rapid load fluctuations.
- Increased peak demand.
- Greater transformer stress.
- Reduced voltage stability margins.

The simulations indicate that the Town Ring 11 kV feeder can accommodate moderate EV penetration levels; however, continued growth without network reinforcement could negatively affect system reliability and operational stability

CHARPTER 5
CONCLUSION

This study assessed the required upgrades on the Town Ring 11 kV feeder in Tororo to support the adoption of e-mobility charging infrastructure.

The findings indicate that EV adoption will significantly increase electricity demand on the feeder over the study period. The resulting charging demand alters the daily load profile, increases peak demand, and contributes to higher feeder loading and network losses.

Load flow simulations performed under baseline, 10% EV penetration, and 30% EV penetration scenarios demonstrated that increasing EV adoption gradually reduces voltage levels and increases transformer loading across the network.

While the existing feeder can accommodate low levels of EV penetration, higher penetration levels may require strategic network reinforcement to maintain acceptable operating conditions.

Furthermore, the growing use of power electronic chargers introduces potential power quality concerns, including harmonic distortion and reduced voltage stability. These factors should be incorporated into future distribution network planning to ensure reliable and sustainable EV integration.

Overall, the study demonstrates that proactive network upgrades and effective charging management strategies are essential for supporting the long-term growth of e-mobility within Tororo.

CHAPTER 6
RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed:

6.1. Network Reinforcement

- ❖ Upgrade overloaded transformers in areas expected to experience high EV charging demand.
- ❖ Install additional distribution transformers near major charging clusters.
- ❖ Reinforce heavily loaded feeder sections through conductor upgrades.

6.2. Smart Charging Implementation

- ❖ Encourage off-peak charging to reduce stress during peak demand periods.
- ❖ Promote time-of-use tariffs to influence charging behaviour.
- ❖ Implement smart charging systems capable of demand management.

6.3. Power Quality Management

- ❖ Periodically monitor Total Harmonic Distortion (THD) at key network locations.
- ❖ Require EV charging installations to comply with harmonic emission standards.
- ❖ Install harmonic filters where necessary.

6.4. System Planning

- ❖ Integrate EV growth projections into future network expansion plans.
- ❖ Continuously update feeder loading studies as EV adoption increases.
- ❖ Prioritize charging station deployment in areas with adequate network capacity.

6.5. Policy Recommendations

- ❖ Develop technical guidelines for EV charging infrastructure connection.
- ❖ Support investment in public charging infrastructure.
- ❖ Encourage adoption of energy-efficient charging technologies.

CHAPTER 7
CHALLENGES EXPERIENCED DURING THE STUDY

Several challenges were encountered during the study:

- Limited availability of localized EV adoption data for Tororo District.
- Dependence on assumptions and national projections for future EV growth forecasting.
- Limited historical data on EV charging behaviour and charging patterns.
- Difficulty obtaining detailed network operational data for all feeder sections.
- Limited information regarding harmonic emissions from locally deployed EV chargers.
- Time constraints associated with field surveys and stakeholder consultations.
- Uncertainty regarding future policy developments and market adoption rates.

Despite these challenges, the study utilized available utility records, field observations, stakeholder consultations, and national e-mobility reports to develop realistic planning scenarios.

CHAPTER 8
AREAS FOR FUTURE WORK

Future studies should consider:

- Detailed harmonic analysis and Total Harmonic Distortion (THD) assessment of EV charging stations.
- Voltage stability analysis under high EV penetration levels.
- Integration of solar photovoltaic systems with EV charging infrastructure.
- Battery energy storage systems for peak load management.
- Vehicle-to-Grid (V2G) applications and their impact on distribution networks.
- Optimal siting and sizing of EV charging stations within Tororo.
- Real-time smart charging and demand response strategies.
- Economic analysis of network reinforcement alternatives.
- Reliability assessment of distribution networks under large-scale EV adoption.

These studies would provide a more comprehensive understanding of the long-term implications of e-mobility integration on Uganda's electricity distribution systems.

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[1] Ministry of Energy and Mineral Development (MEMD), Uganda E-mobility Outlook Report, Government of Uganda, Kampala, Uganda, 2024.

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[6] Uganda Electricity Distribution Company Limited (UEDCL), Town Ring 11 kV Feeder Metering Data, Tororo, Uganda, 25th December 2025.

Appendix.

Figure 5: Transformer meter reading and recording

Figure 6: Current measurement on different phases

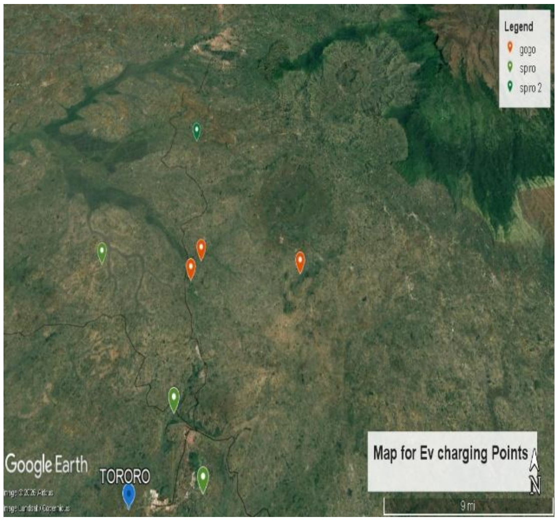

Figure 7: Location of different swapping stations

Figure 8: Field interviewing of boda-boda riders at swapping station

Figure 9:Batteries on charge