Voltage Magnitude Impact of Residential Electric Vehicle Charging: A Case Study in Cusco, Peru

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1. Introduction

Cusco, the historical capital of the Inca Empire, stands today as one of South America's most prominent tourist destinations. With a population of approximately 430,000, the city experiences significant fluctuations in electricity demand, especially during the peak tourist season. These growing energy needs place substantial pressure on Cusco's electrical infrastructure and energy supply systems.

Globally, the adoption of electric vehicles (EVs) has introduced various technical challenges, particularly in their integration into electrical distribution networks. The charging of EVs often affects the infrastructure, causing stress on local grids. However, in cities like Cusco, the secondary impacts of EV adoption remain largely unexplored. This study seeks to address this gap by offering a preliminary analysis of these effects on Cusco's electrical grid.

One of the critical challenges faced during the study was the lack of a robust database necessary for performing computational simulations with tools like OpenDSS [1]. Moreover, the absence of detailed demand profiles, inconsistencies in the database provided by the distribution system operator, and limited information on network topology posed additional hurdles. Georeferencing data was utilized to number the nodes, allowing for a partial reconstruction of the network model. To address these issues, several key actions were undertaken.

First, a database compatible with OpenDSS was developed to enable the simulation of EV connections to Cusco's electrical distribution network. Various EV charging scenarios were then created and analyzed, including both public charging stations and private residential setups. These simulations were instrumental in assessing the impacts of EV integration on the network's voltage profile. Additionally, corrective measures were modeled to address voltage violations observed during the simulations.

This study focuses on three primary objectives:

- Develop a comprehensive database for OpenDSS simulations of EV integration.

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- Simulate multiple EV charging scenarios to evaluate their grid impact.
- Analyze the technical effects, specifically voltage magnitude changes, resulting from EV adoption in Cusco's electrical network.

The remainder of this paper is structured as follows: Section 2 describes the network model, EV and load profiles, and the creation of the circuit in OpenDSS. Section 3 details the case studies used for analysis, with results presented in Section 4. Finally, Section 5 summarizes the main contributions of this study.

2. Methodology

This section begins by describing the distribution network model used in this work. It then presents the EV and load profiles, and lastly the creating of the circuit in OpenDSS.

2.1. Network model

Cusco is supplied by two main substations, Dolorespata and Quencoro, which together supplied the city's total demand. The substation under study is Quencoro (138/34.5/10.5 kV), located in the southern part of the city. Quencoro has seven feeders on the 10.5 kV side and three feeders on the 34.5 kV side, as shown in Appendix A.

For this analysis, the second feeder (QU-02) on the 10.5 kV side was selected. This feeder supplies power to 20 distribution transformers rated at 10.5/0.22 kV. Among these, the distribution transformer SED022 was chosen, which feeds three three-phase circuits and one public lighting circuit. The analysis focused on three-phase Circuit-03, which serves 117 single-phase customers distributed across phases (RS, ST, and TR). Load profiles were adapted for all customers at each load node to ensure accuracy.

The SED022 characteristics are shown in Table 1 and the network model is shown in Fig. 1.

Table 1: System Characteristics

Customers (1-ph)	**LV Lines/Segments (3-ph)**	**Distribution Transformer (3-ph)**	**Frequency**
117	24	10.5/0.22 kV/kV, 250 kVA (D-Y)	60 Hz

To model the topology of the SED022 distribution network, a detailed and organized database was developed using data provided by the distribution system operator in Cusco (Electro Sur Este S.A.A.) [2]. The initial step involved exporting data into tables from ArcGIS [3], which included information on substations, nodes, lines, and customers.

Next, the network topology was constructed using the geographic coordinates (latitude and longitude) of each node. The Python library `networkx` [4] was employed to calculate the network's structure and the distances between nodes, as detailed in Appendix B.

This database served as the foundation for the network simulations and subsequent analyses.

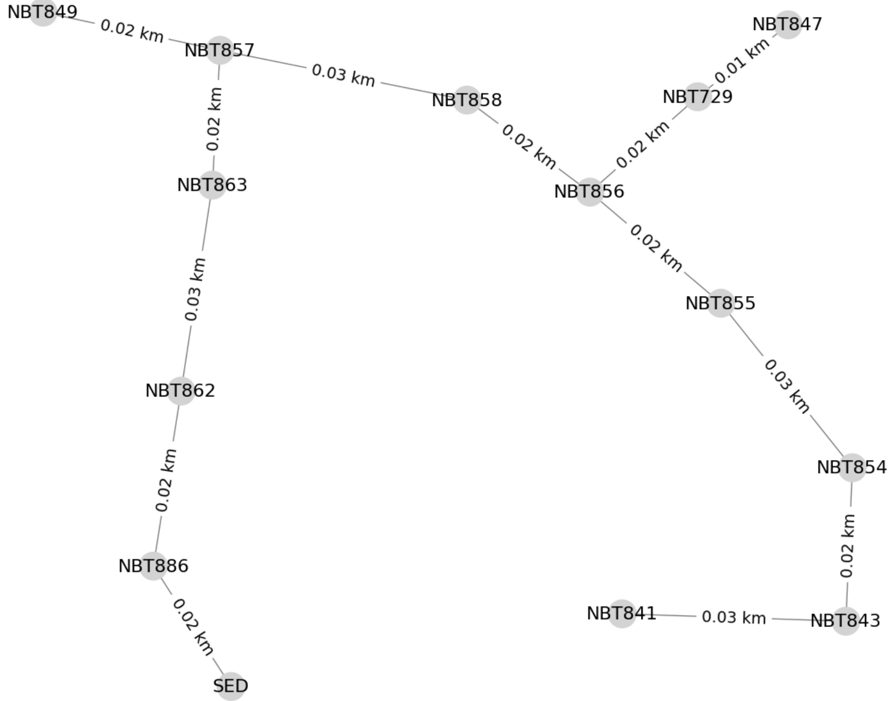


Figure 1: Substation SED022 grid model

Table 2: Characteristics of the BYD EV Dolphin.

Feature	**Specification**
Battery capacity	44.9 kWh
AC charging power	6.6 kW
DC charging power	60 kW

2.2. EV and load profiles

The EV profiles were adapted from [5]. Figure 2 illustrates three EV charging profiles: residential, workplace, and afternoon charging. These profiles were adjusted to reflect the characteristics of the BYD EV Dolphin [6], as summarized in Table 2. Finally, the profiles were scaled to align with the power ratings of the EVs in the dataset.

Note that the charging time for each EV is approximately 7 hours. Additionally, the afternoon charging profile is the only one specifically adapted for a 7-hour charging duration. The residential and workplace charging profiles extend to 10 hours, as they align with typical residential and workplace schedules.

On the other hand, the load profiles were obtained from [7]. Fig. 3 shows the load profiles adjusted for each of the 13 buses. Each profile is associated with a load node in the SED022 substation circuit. For this, the 117 customers were grouped into 13 load nodes,

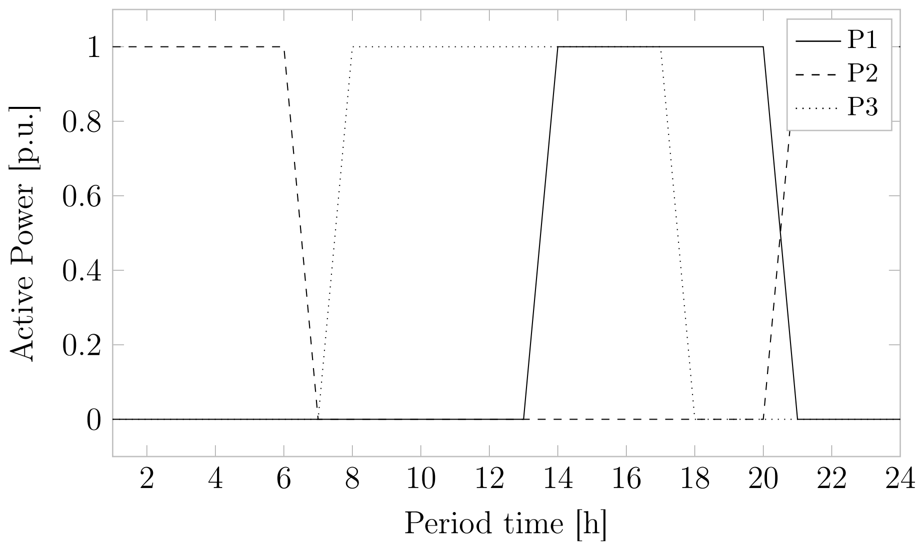


Figure 2: EV profiles

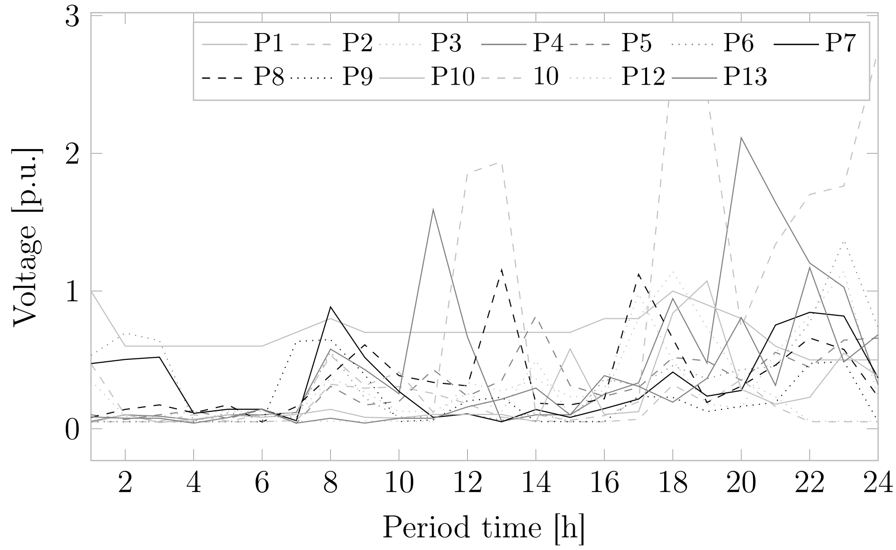


Figure 3: Load profiles

with each node representing an average load of 9 customers. This grouping ensures that the total load corresponds to the 117 customers.

2.3. OpenDSS circuit creation

The circuit was created in OpenDSS [1] using the network model for the EV and load profiles, as explained in previous subsections.

The Python library extension `dss` [8] was used to automate the circuit creation process. Below is a summary of the code used to run the simulation. The complete implementation can be found in the repository referenced in Appendix Appendix C.

```python
import dss

dss_engine = dss.DSS
DSSText = dss_engine.Text
DSSCircuit = dss_engine.ActiveCircuit
DSSSolution = dss_engine.ActiveCircuit.Solution
ControlQueue = dss_engine.ActiveCircuit.CtrlQueue
dss_engine.AllowForms = 0

DSSText.Command = 'Clear'
DSSText.Command = 'Compile ' + mydir +  '/Master.txt'
DSSText.Command = 'Set VoltageBases = [10.5, 0.22]'
DSSText.Command = 'set controlmode=static'
DSSText.Command = 'set mode=daily'
DSSText.Command = 'calcvoltagebases'

DSSSolution.Solve()
if DSSSolution.Converged:
    print("The Circuit was Successfully Solved")
```

Listing 1: Python code to interact with OpenDSS

3. Cases studies

Two case studies were conducted to analyze the impact of residential EV charging on the voltage magnitude of the SED022 substation. The cases are as follows:

- Case 1: Base case scenario with no EVs connected to the grid.
- Case 2: Scenario with 3 EVs (slow charging) connected to the grid.

It is important to mention that DC fast charging was not studied due to the focus on residential charging. Additionally, charging at public electric vehicle stations was not analyzed in this study.

4. Results

To analyze the results, the network under study was simulated to reflect its behavior as realistically as possible. The voltage magnitude was evaluated at the SED022 transformer output and at he NBT857, NBT856, and NBT841 buses to assess voltage drops throughout the network.

In Case I, the voltage profile shows minimal variations at the substation output. However, midway through the network (see Fig. 5b), voltage variations start to appear. At the last node, NBT841 (Fig. 5d), a more significant voltage drop is observed. This is primarily due to

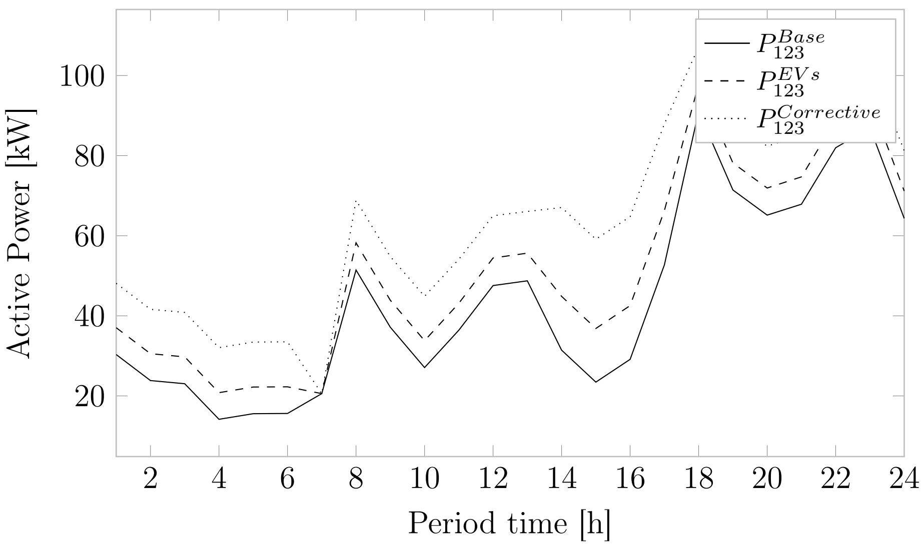


Figure 4: Load profile at the SED022 transformer for Case I, II and corrective solution.

the peak demand period, as shown in Fig. 4. During other periods, these voltage variations are less pronounced. Figure 5 presents the overall voltage magnitudes for the studied nodes and the SED022 transformer.

In Case II, three EVs were added to the studied nodes (NBT857, NBT856, and NBT841). It is important to note that the demand profile, with the inclusion of EVs and their varying charging schedules, accentuates these voltage drops. Additionally, the last nodes experience a more significant voltage magnitude impact, as well as voltage imbalance between phases, as shown in Fig. 6.

The next subsection explained the corrective solutions.

4.1. Corrective solutions

To mitigate the impacts of EV charging on the voltage profile, two corrective measures were analyzed. These solutions aimed to address voltage violations and ensure the magnitude of voltage acrros the entire grid.

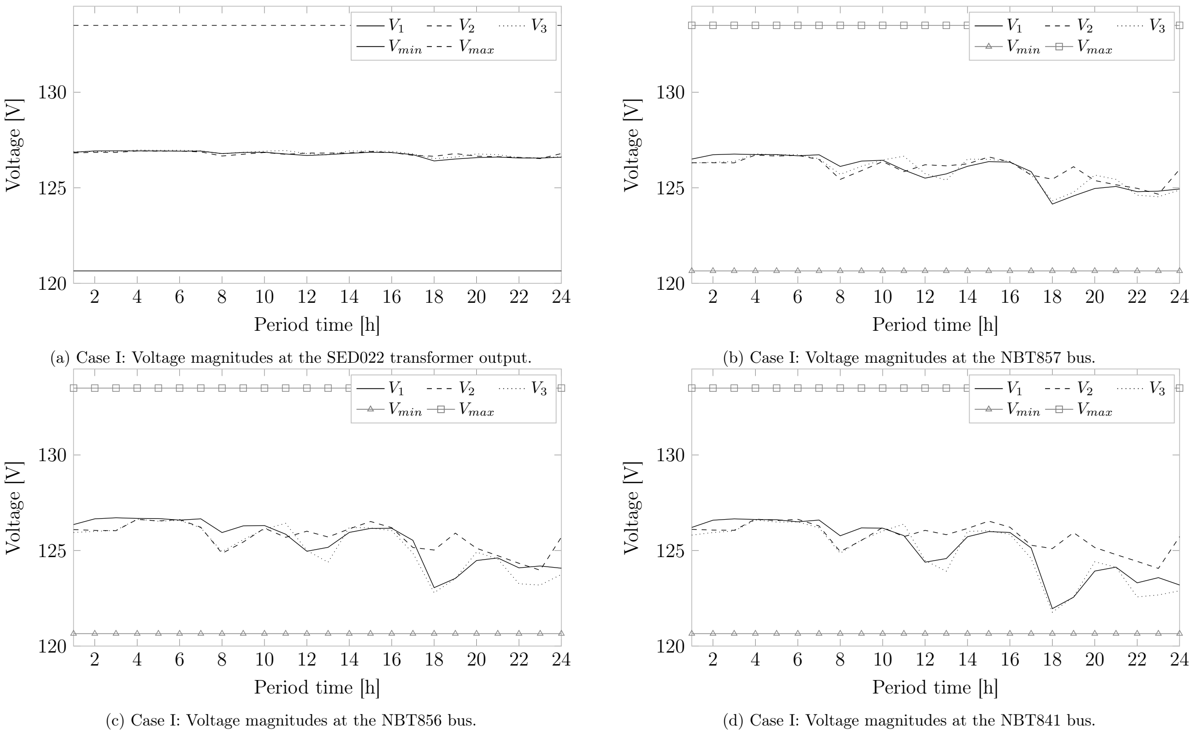
The corrective measures implemented were:

- Converting the charging of the three EVs to a three-phase load.
- Increasing the conductor's cross-sectional area ($25mm^2$ to $120mm^2$).

These actions successfully mitigated the voltage magnitude drop at the studied nodes, as shown in Fig. 7.

5. Conclusions

This work presented a preliminary analysis of the impact of electric vehicle (EV) charging on the electrical distribution network in Cusco. The results demonstrated that:



(a) Case I: Voltage magnitudes at the SED022 transformer output.

(b) Case I: Voltage magnitudes at the NBT857 bus.

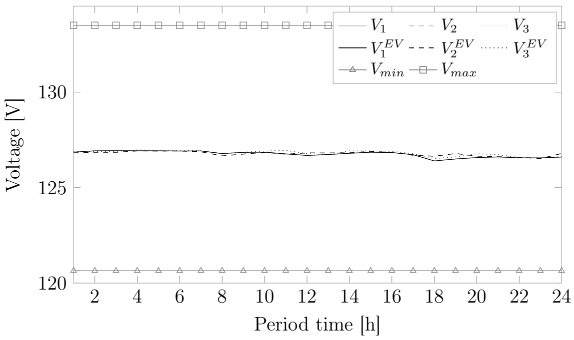
(c) Case I: Voltage magnitudes at the NBT856 bus.

(d) Case I: Voltage magnitudes at the NBT841 bus.

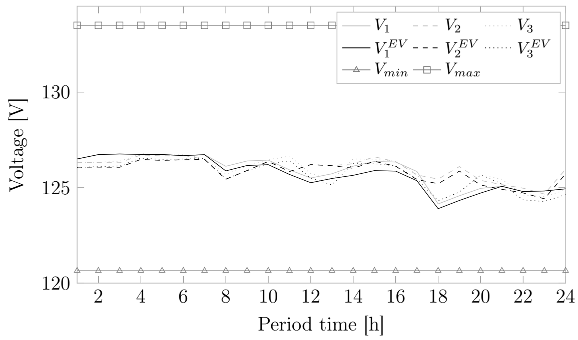
Figure 5: Case I: Voltage magnitudes.

- The integration of electric vehicles into the grid can significantly affect the voltage profile, particularly during peak demand periods. This effect is more pronounced at nodes farther from the substation, where voltage drops become more evident.
- Simulating various charging scenarios revealed that the addition of EVs leads to increased voltage variation, especially at the last nodes in the network. This issue is further exacerbated by the lack of adequate infrastructure to handle the increased demand.
- Corrective measures, such as converting to a three-phase load and increasing the conductor cross-section, were found to effectively mitigate the voltage drop, ensuring that voltage levels remain within acceptable limits.
- The study also highlighted the importance of incorporating realistic demand profiles and charging schedules for EVs to accurately assess the impacts on the network.

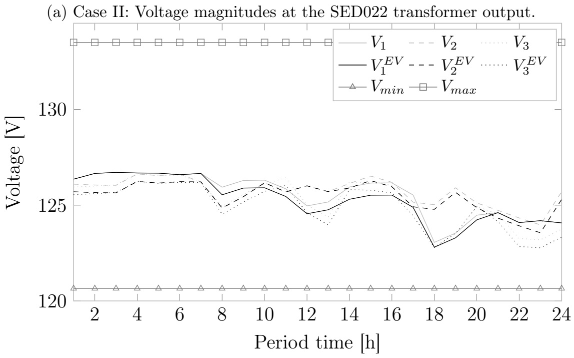
These findings underscore the need for careful planning and infrastructure upgrades to support the growing adoption of electric vehicles. Future studies should focus on refining these models and exploring additional corrective actions, such as reactive power compensation and load management, to further stabilize the grid under varying EV charging conditions.
In conclusion, while EV adoption presents challenges for electrical grids, appropriate solutions can help integrate these technologies in a way that ensures grid reliability and efficiency.



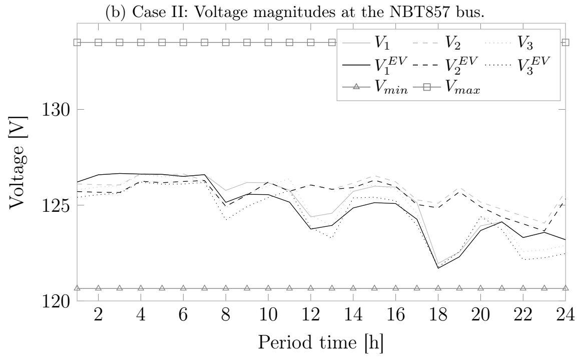
(a) Case II: Voltage magnitudes at the SED022 transformer output.



(b) Case II: Voltage magnitudes at the NBT857 bus.



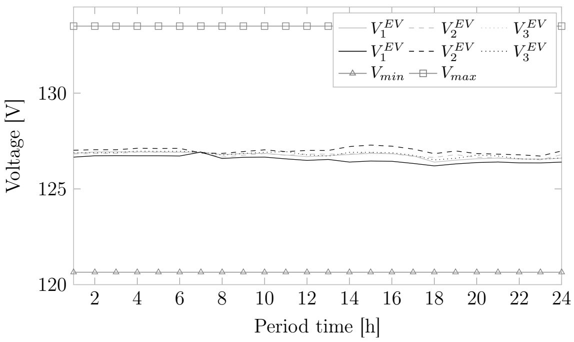
(c) Case II: Voltage magnitudes at the NBT856 bus.



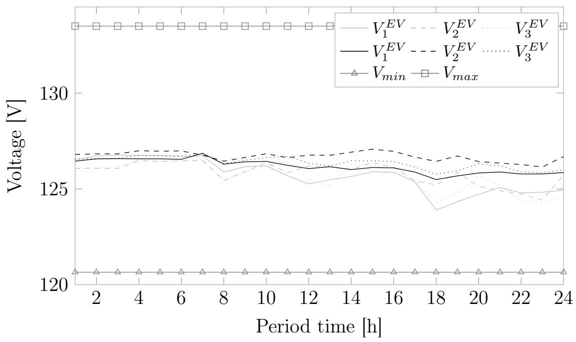
(d) Case II: Voltage magnitudes at the NBT841 bus.

Figure 6: Case II: Voltage magnitudes.

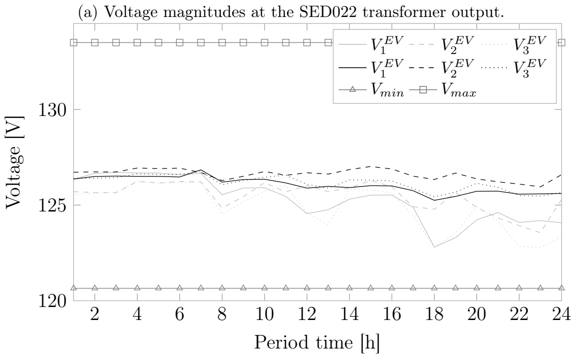
Appendix A. Unifilar diagram of the Quencoro substation



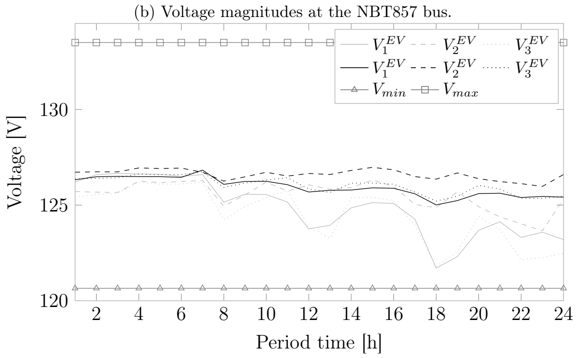
(a) Voltage magnitudes at the SED022 transformer output.



(b) Voltage magnitudes at the NBT857 bus.



(c) Voltage magnitudes at the NBT856 bus.



(d) Voltage magnitudes at the NBT841 bus.

Figure 7: Corrective solution for voltage magnitudes.

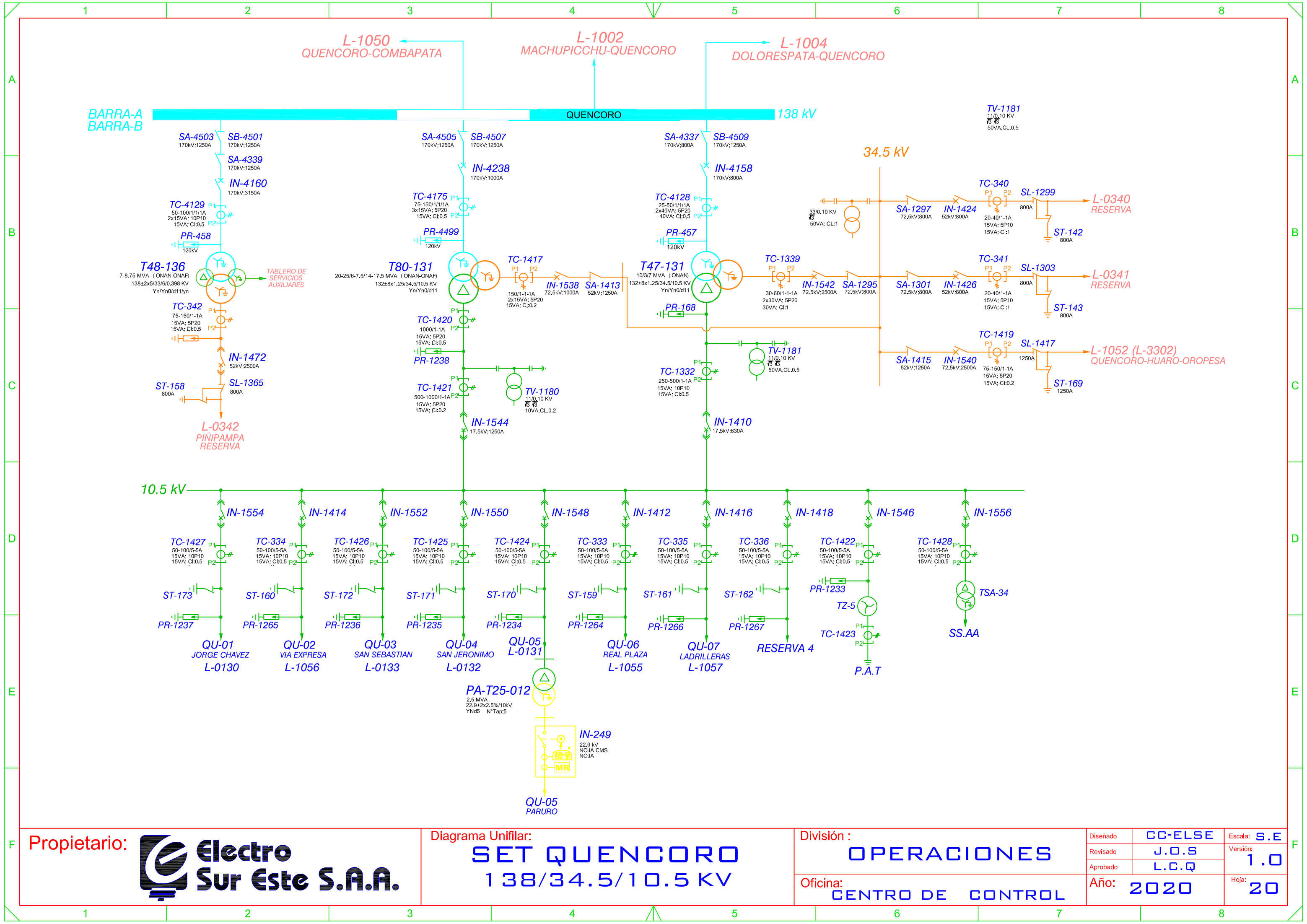


Figure A.8: Unifilar diagram of the Quencoro substation

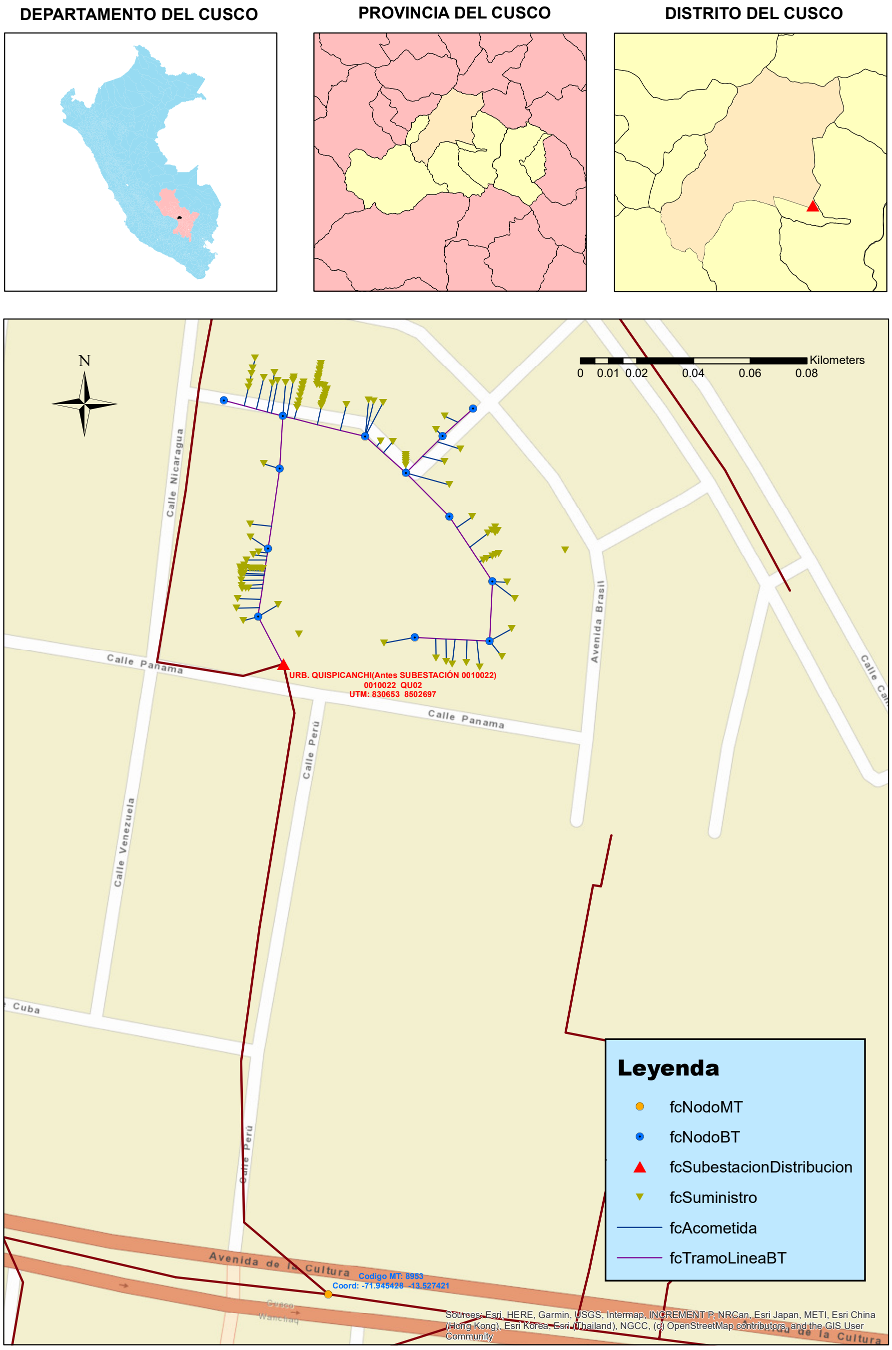


Figure B.9: Topology of the SED022 distribution network

Appendix B. Topology of the SED022 distribution network

Appendix C. Repository with the data and code used in this work

`https://github.com/DerianTairoGarcia/Trabalho_final_IT305_H.git`

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