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| RESEARCH ARTICLE

Impact Analysis of Public Electric Vehicle Charging Stations on Transformers and Distribution Networks

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| ABSTRACT
Public Electric Vehicle Charging Stations (SPKLUs) are critical infrastructure in facilitating the increasingly popular use of electric vehicles. The increasing number of electric vehicles using SPKLU also has an impact on existing transformers and distribution networks. This research uses the Fluke 1748 tool to analyze the impact on transformers and distribution networks. The Fluke 1748 is a tool that can record and analyze electrical parameters such as voltage, current, power, and power factor with high precision. The method used in this analysis involves installing the Fluke 1748 device at strategic points around the SPKLU, transformer, and distribution network. The results of this study are At the public electric vehicle charging station, an analysis has been carried out on the voltage and current where the results of THDV of 2.212% still meet the IEEE 2014 standard and THDi of 4.929% meet the IEEE 2014 standard, the impact caused is that there are losses in kWh sales due to voltage drops or voltage drops of 2250 watts, losses in significant transformers and in the conductor also cause a voltage drop of 2.5% of the nominal voltage**.**

| KEYWORDS

Harmonics, Transformer, Distribution Network, Electric Vehicle

| ARTICLE INFORMATION

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1. Introduction
According to the world energy development model, the fundamental characteristic of energy diversity is electric vehicles; various countries in the world pay attention to electric vehicles, and the international introduction of electric vehicles has brought new challenges to the safety and operation of electricity systems. When many electric vehicles are connected to the grid at peak load, it further increases the load on the power grid and causes greater peak load differences [Han et al., 2014].

The demand for cheaper and more efficient electric vehicles has fueled the growth of Plug-in Hybrid Electric Vehicle (PHEV) technology. In a growing economy, the number of these cars is expected to continue to increase, especially in developed countries. The increase in the number of PHEVs causes undesirable effects such as increased demand, power losses, voltage unbalance, voltage drift, and the need for grid investment [Ghobadzadeh et al. 2020].

Perusahaan Listrik Negara is a government company that has the duty to ensure the availability of good and stable electricity for the community. The company has an important role in providing adequate infrastructure for charging electric vehicle batteries. The Public Electric Vehicle Charging Station (SPKLU) is one of the innovations developed by the company to meet market demand for electric vehicles [PT PLN 2021]. Public Electric Car Charging Station (SPKLU), or Electric Vehicle Charging Station (EVCS), is a place and equipment to recharge the electric car battery [EVCS 2022]. This charging station is, of course, connected to the distribution network and requires a distribution transformer as a distributor of electrical energy from high voltage to low voltage [PT PLN 2020]. As a result of being connected to the distribution network, harmonics will be generated, resulting in power loss, voltage imbalance, voltage deviation and reduced efficiency.

According to research by [Jun, Y., Xuemei, L., et al. 2019], It is concluded that the Electric Vehicle (EV) charging load increases the peak difference of the power grid and makes the power grid voltage drop seriously. According to research by [Andrii, B., Alla, B., et al. 2019], It is concluded that the influence of the charger on the quality of electricity and it is found that the efficiency coefficient is about 55%. According to research by [Kevin G. H. et al. 2019], the charging position of EVs on the grid significantly affects voltage drop conditions. High penetration of EVs will probably cause overload conditions on distribution networks and transformers. According to research by [Martin K. et al. 2019], It is concluded that the 3-phase AC charging system supplies 13% of the reactive power corresponding to the active power of charging. The harmonic fraction in the charging current is more significant and reaches 4.5% of the drawn current value. According to research by [Suwanapingkarl, Prakobkit, et al. 2020], It is concluded that THD levels can be raised due to the combination of RE converters and/or inverters, which operate at less than 10 percent of their rating, and this is also similar to EVs operating at charging mode with low battery levels. Therefore, filter devices such as passive and active are also considered to reduce THD levels in the grid using Passive and Active filters.

Seeing the great influence of previous research, researchers are interested in analyzing the effect of loading on the Public Electric Vehicle Charging Station (SPKLU) installed at the State Electricity Company (PLN) Medan Customer Service Implementation Unit by comparing the charging current of electric vehicles and voltage harmonics using the Fluke-437 Power Quality And Energy Analyzer tool, researchers are also interested in analyzing the impact of electric vehicle charging stations on distribution networks and transformers.

2. Literature Review

Pollution, energy shortages and other issues are gradually attracting people's attention. Electric vehicles (EVs) as environmentally friendly vehicles have developed rapidly. Accurately predicting the charging load of EVs is the basis for analyzing the effects of EVs on the distribution network and the necessary prerequisites for the interaction of EVs on the distribution network and transformers [Jun et al. 2019].

Electric vehicles and conventional electric loads are different; they are distributed energy storage. As a large charging load for electric vehicles, the charging mode has a greater impact on the grid. Electric vehicle power supply methods include slow charging vehicles, fast charging and battery exchange vehicles; different charging methods correspond to significant differences. Trends in different countries and regions in the development of electric vehicles are different, and the scale of development of electric vehicles will determine the general characteristics of electric vehicle charging [Jisheng et al. 2018].

Public Electric Vehicle Charging Station (SPKLU) Electric Vehicle Charging Station (EVCS) is a location adjacent to the electric car battery charger. They are an important part of the global plan for electric car charging for private and public use [EVCS 2022]

2.1 Types of Electric Car Charging Sources

The types of electric car charging sources can be grouped as follows:

1. 1 phase slow charging (AC slow charging)
   1 phase slow charging usually requires multiphase conversion (i.e. AC-DC and DC-DC), resulting in low voltage and relatively high output power
2. Fast charging (AC fast charging)
   Compared with slow charging technology, fast charging technology can provide faster charging opportunities due to reasonable power (about 20kW); this means they can charge the battery up to 80%, and charging time varies between 2 to 3.5 hours. [Qasem et al 2021]
3. Direct current charging (DC Charging)
   This filling can be classified into two parts [Qasem et al. 2021]:
   Off-Board Fast Charging. This type of technology is very popular because the charging system is very fast, the power source used is in the range of 20 kW-120 kW, and the DC battery voltage is 320 V-450 V.
4. Direct current super fast charging (Off-Board Rapid Charging).
   This technology was developed from fast charging where the battery voltage is 320 V-500 V DC and used at 250 kW power.

2.2 Working System of SPKLU Electric Car Charger

The charging system is shown in Figure 1. The configuration shows the integration of the grid with the EV battery and the non-linear load. The grid operates a non-linear load created using a diode bridge rectifier followed by R and L. The grid is connected to a bidirectional transformer through a voltage source converter (VSC) via a common coupling capacitor. The VSC converts AC power from the mains into DC power, which is then fed to the bidirectional converter to feed the electric car battery. The bidirectional converter is connected to the EV battery via a smoothing coil. A medium resistance, ultra-low capacitance ripple circuit is used to reduce high-frequency noise in the mains voltage [Dulichand et al. 2022].

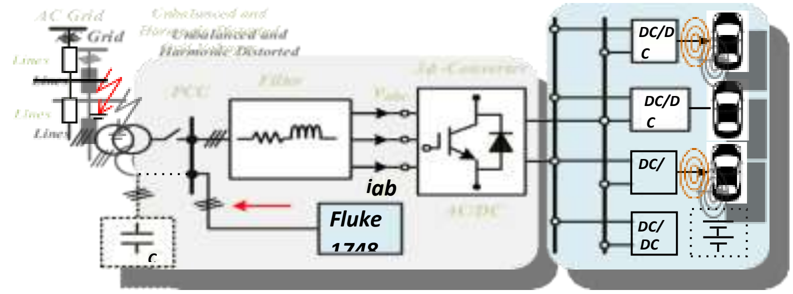

Figure 1 Circuitry of the Charging System

2.3 Harmonisa

The term "harmonic" comes from the field of acoustics, which refers to the vibration of a band or column of air at frequencies that are multiples of the fundamental frequency. The harmonic component of an AC system is defined as the sinusoidal component of a periodic waveform with a frequency equal to an integer multiple of the fundamental frequency of the system. Harmonics in the form of voltage or current can then be understood as perfect sine components with frequency multiples of the fundamental frequency, which can be calculated using Equation 2.5.[Rosa et al. 2006]:

$$f_h = (h) \times (\text{Base Frequency})$$

2.4 Transformator

The operating principle of a transformer can be explained by electromagnetic induction, where there is a magnetic connection between the primary side and the secondary side. This magnetic coupling takes the form of an iron core through which a mutual current is guided. Magnetic fields play a very important role in several energy conversion processes. With the help of magnetic fields, a form of mechanical energy can be converted into electrical energy - this conversion tool is called a generator or vice versa from a form of electrical energy into mechanical energy as this conversion tool is called a motor [20]. Transformers use electromagnetic principles, namely Ampere's law and Faraday induction, where changes in a current or electric field can cause a magnetic field, and changes in magnetic field / magnetic flux can cause induced voltage.

2.5 Transformer Working Principle

In the working principle of the transformer, the main parts are primary coil, secondary coil and transformer core. The coil surrounds the iron core in the form of a coil. When the coil on the primary side of the transformer is connected to a sinusoidal alternating voltage source (Vp), an alternating current will also flow sinusoidally (Ip) in the coil. This alternating current will cause magnetic flux (Φ), which is in phase and sinusoidal around the coils.

Transformers can increase or decrease voltage depending on the number of wire turns. To increase the voltage, the number of primary or transformer windings must be less than the number of secondary windings. Meanwhile, if you want to reduce the voltage, the number of primary windings of the transformer must be more than the number of secondary windings. For illustration, the Traformator can be seen in Figure 2.

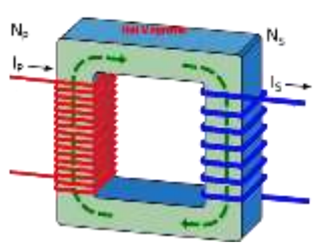

Figure 2. Scheme of Transformator

2.6 Current and Voltage Harmonic Standards

The allowed VTHD standard is set according to the Point of Common Coupling (PCC), where each voltage level has a different standard, as well as the ITHD, which is set with different standards according to the PCC and the short circuit ratio calculation. The IEEE 519-2014 standard is a standard that contains limits on the harmonic content contained in the power system, both voltage harmonics and current harmonics. The suggested limit will be applied according to the Point Of Common Coupling (PCC) between the owner and the user.

2.7 Harmonics in Distribution Transformers
Transformer losses consist of "no-load losses", which depend on the peak flux level required to magnetize the transformer core and are negligible with respect to harmonic current levels, and "load losses", which increase significantly at harmonic frequencies when the transformer supplies nonlinear currents [American Bureau of Shipping 2006].

The effect of harmonic currents at harmonic frequencies in transformers leads to an increase in core losses through an increase in iron losses (i.e. eddy currents and hysteresis).

3. Methods
In this study, researchers will analyze the impact of public electric vehicle charging stations statistically on transformers and distribution networks. The research flow chart can be seen in Figure 3

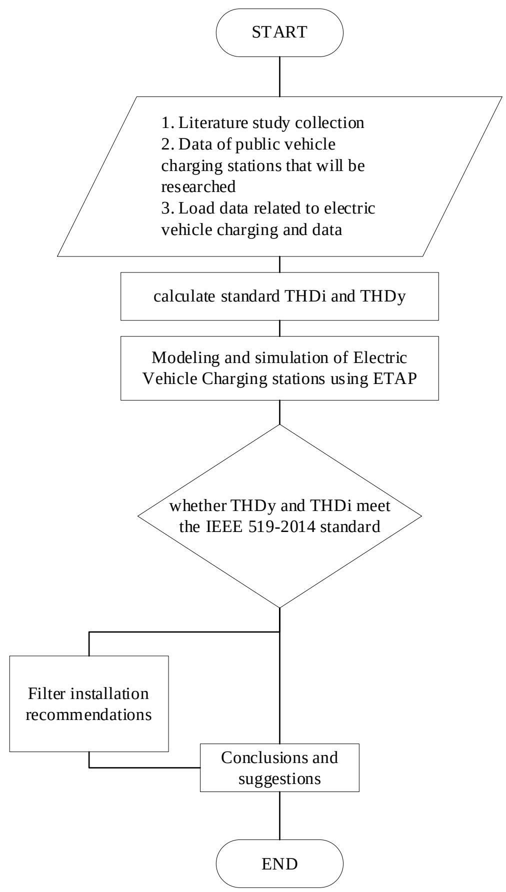

Figure 3 Research flow chart

To carry out research, of course, supporting data is needed. This research data collection is located at PT PLN (Persero) UP3 Medan Jalan Listrik No.08, Medan. The implementation time of this research was carried out ± 5 (five) months.

3.1 Tools and Materials
The tools and materials that will be used in this research are as follows:

3.1.1 Public Electric Vehicle Charging Stations
This equipment is an electronic circuit that converts AC voltage to DC for electric car charging needs, as shown in Figure 4.

Figure 4 Model of SPKLU Charging Electric Car

The specifications of the Electric Car Charging SPKLU are as follows:
Tipe Charging: EVDE25D4DUM
Rev : S08
Input : 3 Phasa + N +PE, 380 -415V 50A Maximum
Frekuensi : 50/60 Hz
Output :50-500 Vdc, 60 A MAXIMUM
Max Output : 25 Kw
Temperatur : 500 C MAX
S/N : ZJ3212100226W0

3.1.2 Measuring and Limiting Devices (APP)

Measuring and limiting devices are used as measurements of the amount of current used and as a limiter in the event of a load surge.

Gambar 5 Alat Pengukur dan Pembatas (APP)

3.1.3 Multitester

Multitester is used as a measurement of the voltage flowing when the public electric vehicle charging station works; the multimeter used is the 2017 HIOKI multimeter with Type CM3286-01.

Figure 6. Multitester

3.1.4 Fluke-437 Power Quality and Energy Analyzer

Harmonics measuring instrument using fluke-437 Power Quality and Energy Analyzer used to measure current and voltage harmonics of the 1st, 2nd and 3rd order,

Figure 7 1Fluke-437 Power Quality and Energy Analyzer

3.1.5 Fluke 437 Laptop and Application

A laptop is used for data storage and processing data received from Arduino Uno R3, Fluke-437 Power Quality and Energy Analyzer and Fluke VT02 visual IR thermometer.

Procedure This measurement was carried out on the PCC where the Fluke-437 Power Quality and Energy Analyzer was installed before the SPKLU Charging Electric Car. The form of research testing is to determine the load characteristics generated by the Public Electric Vehicle Charging Station.

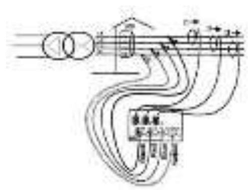

Figure 8 *Testing Scheme on SPKLU Charging Electric Car*

4. Result and Discussion

4.1 Public Electric Vehicle Charging Station System Simulation

In electric vehicle charging systems, charging up to 70 kW is always possible using only one connector, while the others are blocked during charging. Figure 4.1 shows the block diagram of the charging system from the DC side of the station. At the input, there is a 3-phase rectifier that ensures symmetrical current consumption from the distribution network. This returns again to a high frequency voltage (20 to 100 kHz) and is directly switched to the battery voltage. Charging allows an output DC voltage ranging from 50 V to 500 V.

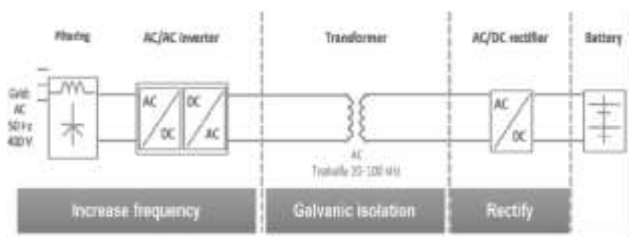

Figure 9 Block diagram of charging system from DC station side

Figure 10 Diagram of installed Electric Vehicle Charging Station System

Figure 10 shows the electronic devices installed at the Public Electric Vehicle Charging Station (SPKLU), where electronic components can convert the AC system to DC so that it can be used for charging electric vehicles.

4.2 Public Electric Vehicle Charging Station System Measurement

All the Public Electric Vehicle Charging Station (SPKLU) systems were chosen to be located closer to the distribution transformer and connected by a separate cable directly from the low voltage distribution substation, where it is expected that there is no voltage drop and other parameters related to the assessment of the quality of electrical energy from a standard point of view. A parameter to consider is the adequate capacity of the transformer.

In measuring the Public Electric Vehicle Charging Station system using Fluke 437, which is assembled according to Figure 3.7 where, the results obtained by Fliker on the voltage shown in Figure 11.

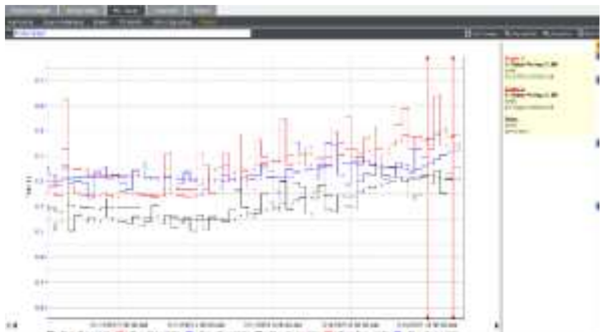

Figure 11 SPKLU bumper Flicker

In Figure 11, there is a flicker during the charging process of electric vehicles up to 6% (percent) of the nominal voltage due to this fliker causing a voltage drop. A recap of the voltage drop that occurs is shown in Figure 12

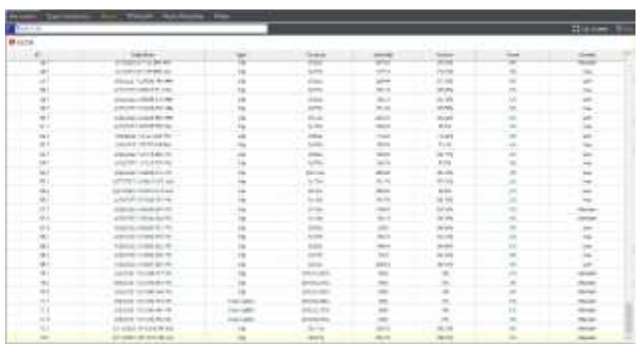

Figure 12 Voltage Drop Recap

If there is a voltage drop, it will affect the kWh generated; this voltage drop can affect the calculations in Equation 2.1, Equation 2.2, Equation 2.3, Equation 2.4 and Equation 2.39, where voltage greatly affects and can reduce kWh sold. This can be exemplified using the calculation in Equation 2.2, where we assume if the current is according to the specifications of the Electric Vehicle Charging Station shown in Figure 3.2 where the current is 50 A, then:

$$P = V \times I \times \cos \varphi$$
$$P = 160 \times 50 \times 0{,}85 = 6800 \text{ Watt}$$

If normal stress is used, then:

$$P = V \times I \times \cos \varphi$$
$$P = 220 \times 50 \times 0{,}85 = 9350 \text{Watt}$$

From here, we see that if there is a voltage drop, it causes a loss of 9350 - 6800 = 2550 Watts.

In the case of a voltage drop, it will also affect the system on the distribution network and transformer. Figure 412 shows the length of time and percentage of the amount of voltage drop caused by the flicker.


Figure 13 Total Voltage Drop

4.3 Measurement of Harmonics in Voltage

Harmonics generated by the voltage can be measured using fluke 437; the results are shown in Figure 4.6, where the harmonics of the voltage are in the highest position, namely harmonic 3 with a value of 1.086% and harmonic 5 with a value of 1.664% and THDv with a value of 2.212% where the THDv standard still meets the standard according to Figure 13 This calculation can be done using the Equation.

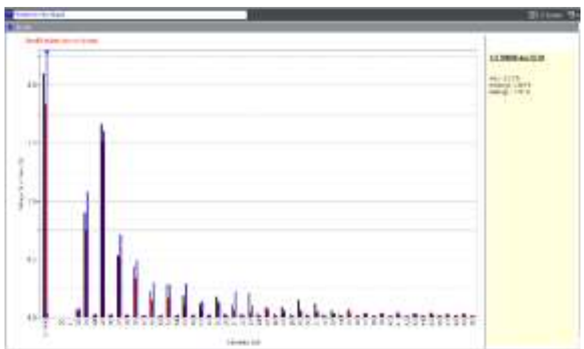
Figure 14 THDv Measurement Using Fluke 437

The voltage waveform can be seen in Figure 14, where harmonics greatly affect the waveform.

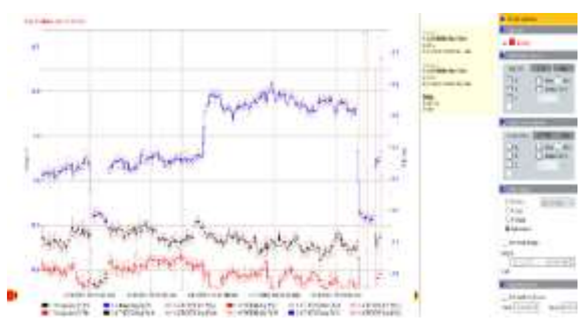
Figure 15 Waveforms on Voltage

Figure 15 shows the voltage unbalance graph where the highest position is at 1.559%.


Figure 16 Voltage Unbalance Graph

4.4 Measurement of Harmonics in Current

Harmonics generated by the current can be measured using Fluke 437 results shown in Figure 16, where the harmonics of the current are in the highest position, namely harmonic 3 with a value of 3.233% and harmonic 5 with a value of 2.662% and THDi with a value of 4.929% where the THDi standard meets the standard.

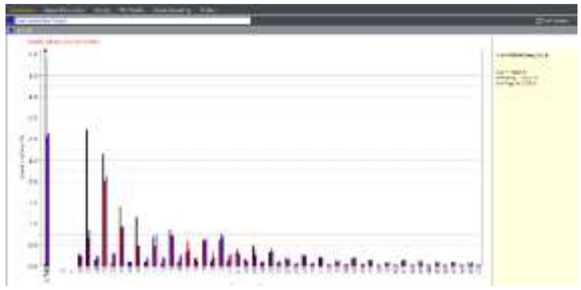

Figure 17 THDi Measurement Using Fluke 437

Figure 17 shows the current waveform and THDi

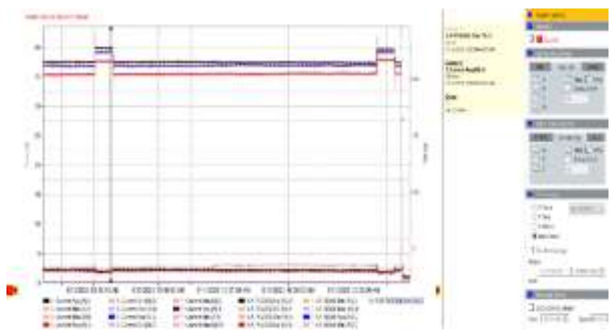

Figure 18 Current Waveform

Figure 18 shows the current unbalance graph where there is often a momentary current drop.

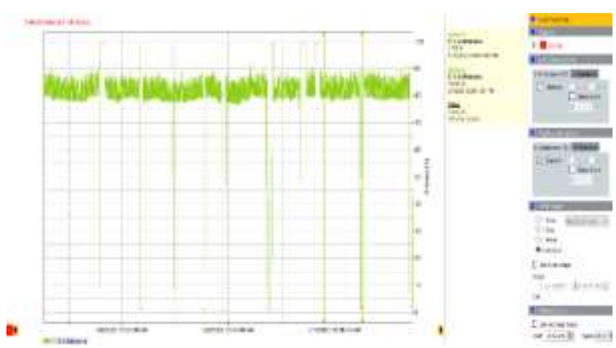

Figure 19 Current Unbalance Graph

Figure 18 and Figure 19 show the energy used and the voltage recorded when taking measurements.

Figure 20 V, A, Hz, THD overview table

Figure 21 Unbalance overview table

4.5 Simulation Using Etap

In this study, researchers made simulations using the ETAP simulator, where simulations were carried out to determine if the Public Electric Vehicle Charging Station (SPKLU) system worked simultaneously and what effects would be caused on the transformer and distribution network. The ETAP simulation can be seen in Figure 22.

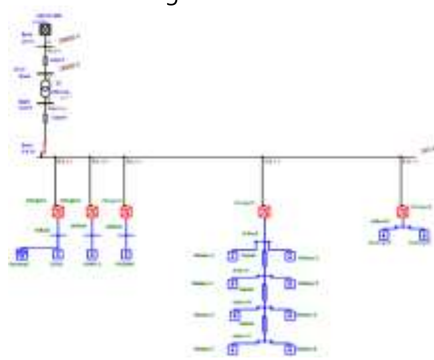

Figure 22 Etap Simulation

In the above simulation, the results of losses are shown in Figure 23

Branch Losses Summary Report

Branch ID	From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop in Vmag
	MW	Mvar	MW	Mvar	kW	kvar	From	To	
Cable1	0.086	0.054	-0.086	-0.054	0.0	0.0	100.0	100.0	0.00
Cable2	0.085	0.053	-0.085	-0.053	0.3	0.1	98.5	98.3	0.26
T1	0.086	0.054	-0.085	-0.053	0.9	1.4	100.0	98.5	1.48
					1.2	1.4			

* This Transmission Line includes Series Capacitor.

Figure 23 Losses based on ETAP

From Figure 23, we can calculate the cost due to Transformer losses using Equation 2.36 where the tariff of 1 kWh is Rp.1415.01, and the tariff of 1 kVArh is Rp.1522.88 then:

BL = PT x 8760 x BKWH = 0.9 x 8760 x 1415.01 = Rp.11.155.938-
BL = PT x 8760 x BKVRH = 1.4 x 8760 x 1522.88 = Rp.18.676.600-

The total cost of transformer loss is Rp.29,832,538-.

Figure 24 shows the current source of harmonics, and Figure 25 shows the source of branch information from harmonics.

Harmonic Library

Current Harmonic Source in %

Manufacturer: Typical-IEEE
Model: 6 Pulse1

Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %	Order	Freq. Hz	Mag. %
1.00	50.00	100.00	5.00	250.00	20.00	7.00	350.00	14.30	11.00	550.00	9.10	13.00	650.00	7.70	17.00	850.00	5.90
19.00	950.00	5.30	23.00	1150.00	4.30	25.00	1250.00	4.00	29.00	1450.00	3.40	31.00	1550.00	3.20	35.00	1750.00	2.80
37.00	1850.00	2.70	41.00	2050.00	2.40	43.00	2150.00	2.30	47.00	2350.00	2.10	49.00	2450.00	2.00			

Figure 24 Harmonic library

System Harmonics Branch Information

Bus		Current Distortion											
From Bus ID	To Bus ID	Fund. Amp	RMS Amp	ASUM Amp	THD %	TIF	IT Amp	ITB Amp	ITR Amp	TIHD %	TSHD %	THDG %	THDS %
Bus1	Bus2	2.92	3.04	5.51	29.01	740.05	2251.39	2251.39	0.00	0.00	0.00	29.01	29.01
Bus2	Bus1	2.92	3.04	5.51	29.01	740.05	2251.39	2251.39	0.00	0.00	0.00	29.01	29.01
	Bus4	2.92	3.04	5.51	29.01	740.05	2251.39	2251.39	0.00	0.00	0.00	29.01	29.01
Bus4	Bus5	146.09	152.11	275.31	29.01	740.05	112569.50	112569.50	0.00	0.00	0.00	29.01	29.01
	Bus2	146.09	152.11	275.31	29.01	740.05	112569.50	112569.50	0.00	0.00	0.00	29.01	29.01
Bus5	Bus4	146.09	152.11	275.31	29.01	740.05	112569.50	112569.50	0.00	0.00	0.00	29.01	29.01

Figure 25 Branch Information of Harmonics

5. Conclusion

From the results of the research conducted, the following conclusions can be drawn:

1. At the public electric vehicle charging station, an analysis has been carried out on the voltage and current where the results of THDV of 2.212% still meet the IEEE 2014 standard and THDi of 4.929% meets the IEEE 2014 standard. When charging electric vehicles, there is a voltage drop that can affect calculations related to voltage.
2. The impact of the electric vehicle charging station is:
   a. There are losses in kWh selling due to a voltage drop or a fall in voltage of 2250 watts.
   b. There is a significant loss on the transformer from the use of public electric vehicle charging stations, amounting to Rp.29,832,538-.
   c. The Etap simulation shows that the conductor must be adjusted to the total demand when charging; the conductor can also cause a voltage drop of 2.5% of the nominal voltage.

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Conflicts of Interest: The authors declare no conflict of interest.
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