Feasibility Study of Charging Stations Using Renewable Energy-Based Electricity and Solar PV Systems for Transjakarta

Supporting Jakarta's Transition to E-Mobility

May 2021

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Executive Summary

As part of the study, analysis has to be conducted to ensure that the grid is able to serve the charging load as planned by Transjakarta, in terms of capacity and infrastructure. The charging load takes into account all charging locations including Depot, Terminal, and Staging Facility. Thus, this report calculates the total charging demands of Transjakarta's e-bus fleet deployment and assesses its feasibility to be connected to the local power grid in Greater Jakarta.

Three charging locations i.e. Depot Cijantung, Terminal Ragunan, and Staging Facility Pejaten representing different charging location's type are analyzed. The assessment focuses on comparing the total demand for electric bus charging with the available power reserve capacity of the grid serving Greater Jakarta. Initially, simulation of daily load curve and solar PV production is performed to determine the charging demand in each charging location's representative. The result is later scaled up according to the number of electric buses and bus battery capacity mix for each charging location, to find the total grid power demand for all locations. The total demand is compared with grid's reserve capacity to determine the maximum power demand available to be served by PLN's grid. The peak load for each location's type is also observed and compared with PLN's daily supply curve, ensuring the grid power peak load is within PLN's grid capacity.

This report finds that total charging power demand for all charging locations is 93.44 MW or only 1.3% from total current Jakarta's grid reserve capacity (7,510 MW). Most of the power demands come from depot charging. The charging power peak load occurs during midnight and is estimated to be 160 MW, representing only 3.5% of current Jakarta's peak load. If the solar PV system is placed on the location, the total electricity demand for all locations will reduce by 2.6% from 642.58 MWh/day (without solar PV or full grid supply) to 626.13 MWh/day. The overall electricity demand for charging contributes to less than 0.5% from the grid's reserve capacity (180.24 GWh/day). In brief, the overall charging demand from all locations will not create a significant impact to the grid.

In addition, the required infrastructure to cater electricity charging demand and estimated power connection costs to PLN UID Jakarta are also analyzed and discussed. Our analysis finds that to cover the charging demands at each location (i.e., Depot Cijantung, Terminal Ragunan, and Staging Facility Pejaten) a medium-voltage connection to 20 kV medium-voltage network is required. According to the analysis, it will require at minimum a power connection of 9.40, 0.33 and 4.44 MVA for depot, terminal and staging facility respectively. More importantly, building a new medium-voltage distribution panel (MVMDP) at the customer site is required for all three charging locations, i.e., Depot Cijantung, Terminal Ragunan, and Staging Facility Pejaten, as the load served is high and there is no existing infrastructure capable of supplying the demand. An upgrade of the existing low-voltage distribution panel (LVMDP) might also be required for Depot, as the charging demand is considerably large. In terms of power connection costs—which includes connection fee (*Biaya Penyambungan*, "BP") and subscription guarantee fee (*Uang Jaminan Langganan*, "UJL") to PLN as well as SLO certification fee to a third-party certification body—Depot Cijantung bears the highest estimated total cost at IDR 7.8 billion, followed by Staging Facility Pejaten at IDR 3.7 billion and Terminal Ragunan at IDR 281 million.

1. Introduction

This section outlines the objective, scope of analysis, and the report structure for the "Grid Capacity Requirement for E-Bus Deployment" report.

Objectives

This report is the second part of a two-part study that looks at the feasibility of electric buses charging infrastructure by also implementing renewable energy, especially solar PV. This report focuses specifically on the analysis of the power system to ensure that the grid capacity can match the charging needs for Transjakarta's e-bus fleet deployment. Hence, the main objective of this report are:

1. To analyze the current (local) grid capacity, especially in Jakarta region, and to estimate the electricity demand for electric bus charging, comparing the supply–demand balance of power given Transjakarta's e-buses deployment plan
2. To identify the required electrical power infrastructure at different charging locations (i.e., bus depots, terminals, and staging facilities) to cater the electric buses charging demand

Scope of analysis

This report looks at the charging demand depending on the previously proposed charging scenarios in Deliverable 4.1 ("Assessment Report on the Supporting Infrastructure for E-buses Including the Potential Energy from Renewable Sources and Related Incentives) and to analyze the impact of this charging demand to the local power grid (Jakarta region).

- Current charging location types
- Impact of electric bus charging load to local grid

Report structure

This report is structured as follows:

- Section 2 provides an overview of power system in Greater Jakarta, including the distribution and transmission network, current power demand, and supply capacity
- Section 3 details the methodology used for conducting the analysis of supply-demand balance of power
- Section 4 presents the comparison analysis between power charging demand in all locations with the grid power supply capacity
- Section 5 discusses required infrastructure upgrade to cater the electric bus charging demands on each charging scenario (depot, terminal, and staging facility)
- Section 6 details the assessment of cost associated with power connection to PLN
- Section 7 concludes the key takeaways of the analysis for decision makers (especially Transjakarta) for their electric buses deployment (and charging infrastructure) strategies

2. Overview of Jakarta's power system

Power systems in Indonesia, based on their interconnection, can be categorized into two types: interconnected systems and isolated systems. Interconnected system represents multiple electrical systems that are connected to create one large system. On the contrary, an isolated system is a standalone system without interaction with another electrical system, e.g. electrical system on an island. There are at least two interconnected power systems on the main islands: Java-Madura-Bali system (the largest) and Sumatra system (so far excluded Riau islands, Nias island and Bangka-Belitung). On Kalimantan and Sulawesi island, there are two big systems each, which are planned to be interconnected in the near future. Other than the systems mentioned above, other power systems in Indonesia can be categorized as isolated systems. Indonesia's power system is managed by Perusahaan Listrik Negara (PLN), a state owned enterprise with sole authority to provide electricity to all Indonesian people.

In serving the electricity demand, PLN produces electricity from its own power plants or purchases the electricity from Independent Power Producers (IPPs). Subsequently, PLN delivers the generated electricity to customers through an extensive transmission and distribution network (see Figure 1). The transmission system in Indonesia consists of 500 kV, 230 - 275 kV, 150 kV, and 66 - 70 kV. Each level of voltage is bridged by substations (*"Gardu Induk", "GI"*). Meanwhile, the distribution system consists of:

- Medium Voltage Network ("*Jaringan Tegangan Menengah*", or "JTM"): JTM functions to supply electricity with 20 kV from secondary substations or step-up transformers to medium voltage customers (industry, big customers, etc)
- Low Voltage Network ("*Jaringan Tegangan Rendah*", or "JTR"): JTR functions to supply electricity to TR (low voltage) consumers with a voltage of 220/380V
- Distribution Substation ("*Gardu Distribusi*")
- Service connection
- and apparatus

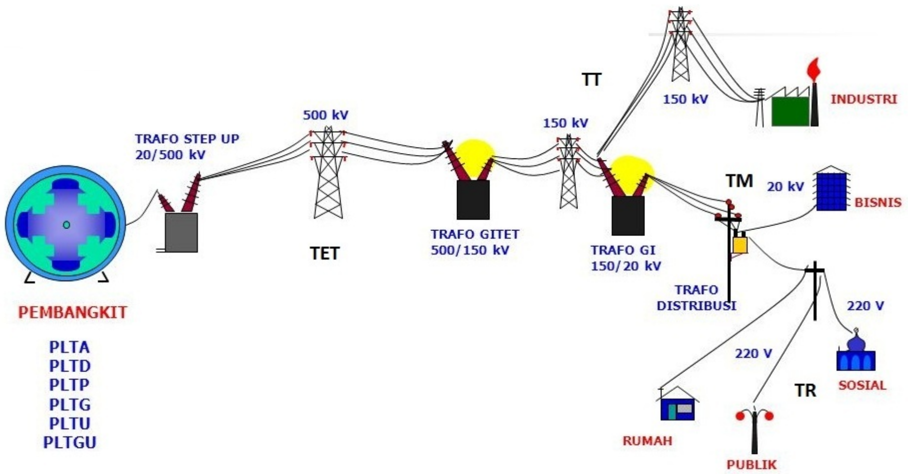
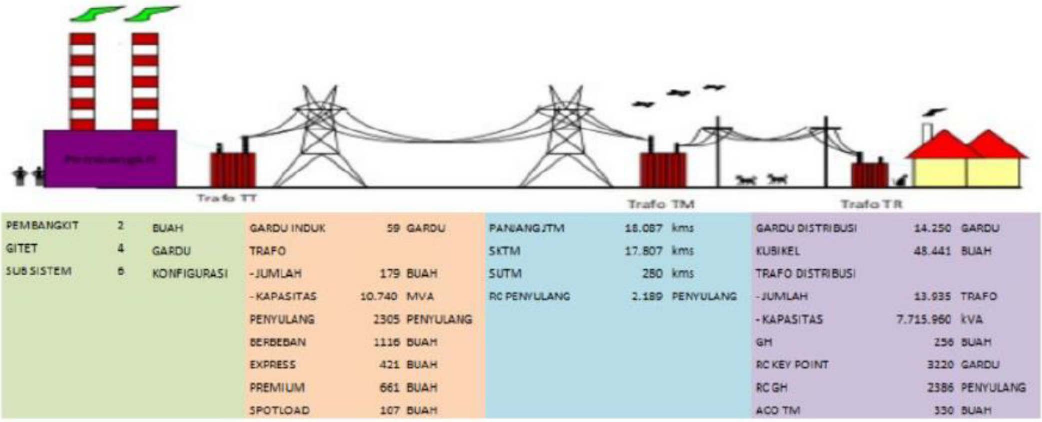


Figure 1. Schematic of Indonesia's Interconnection System (source: Febryan45 (via Wikimedia Commons), distributed under a CC BY-SA 4.0 license)

By the end of 2019, the total number of generating units and installed capacity in Java-Madura-Bali system is 451 units and 40.18 GW respectively (around 64% from total Indonesia's installed capacity)

(PLN, 2020). The Java-Madura-Bali interconnected network consists of two sub-systems, namely Extra-High Voltage Transmission Lines (“*Saluran Udara Tegangan Extra Tinggi*”, or “SUTET”) 500 kV as the main backbone and High Voltage Transmission Line (“*Saluran Udara Tegangan Tinggi*”, or “SUTT”) 150 kV as a support network (see Figure 2). The SUTET spans for 5,092 kms and the SUTT for 15,501 making a total of around 20,500 kms of transmission lines length (MEMR, 2020).



PEMBANGKIT	2	BUAH	GARDU INDUK	59	GARDU	PANJANG JTM	18.087	kms	GARDU DISTRIBUSI	14.250	GARDU
GITET	4	GARDU	TRAFO			SKTM	17.807	kms	KUBIKEL	48.441	BUAH
SUBSISTEM	6	KONFIGURASI	-JUMLAH	179	BUAH	SUTM	280	kms	TRAFO DISTRIBUSI		
			-KAPASITAS	10.740	MVA	RC PENYULANG	2.189	PENYULANG	-JUMLAH	13.935	TRAFO
			PENYULANG	2305	PENYULANG				-KAPASITAS	7.715.960	kVA
			BERBEBAN	1116	BUAH				GH	256	BUAH
			EXPRESS	421	BUAH				RC KEY POINT	3220	GARDU
			PREMIUM	661	BUAH				RC GH	2386	PENYULANG
			SPOTLOAD	107	BUAH				ACO TM	330	BUAH

Figure 2. Detail on Jakarta’s power system (PLN UID Jakarta, 2021)

According to PLN’s 2019 RUPTL (power development plan), Jakarta’s electricity system is supplied from two nearby combined cycle power plants (“*Pembangkit Listrik Tenaga Gas Uap*”, or “PLTGU”) located in Muara Karang and in Tanjung Priok, which is connected through a 150 kV connection, and is also connected through a 500 kV connection to Java–Bali system spread over *six* extra-high voltage transmission substations (“*Gardu Induk Tegangan Ekstra Tinggi*”, or “GITET”) which are located in Gandul, Kembangan, Cawang, Bekasi, Cibinong, and Depok (with a total of declared net capacity “*daya mampu*” of 9,520 MW) (PLN UID Jakarta, 2021). Figure 3 represents Jakarta’s power system map as of November 2018 listed in the RUPTL 2019-2028.

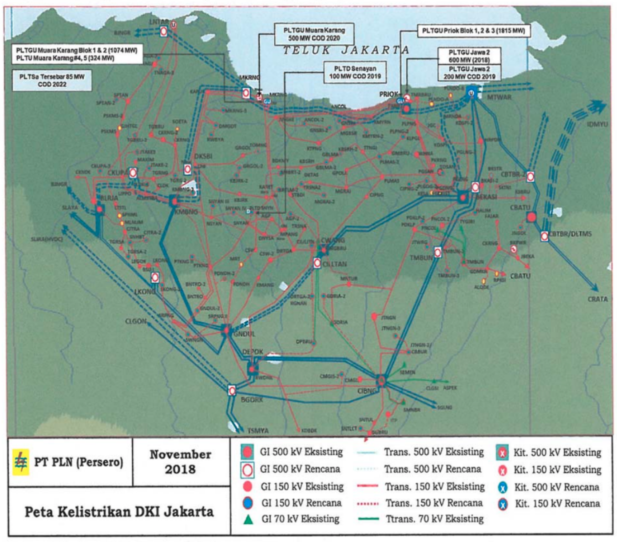


Figure 3. DKI Jakarta’s electric power system map (Source: PLN’s RUPTL 2019–2028)

Electricity system in Jakarta is further divided into six sub-system, that is:

1. GITET Bandul and PLTGU Muara Karang supply South Jakarta, Central Jakarta, and part of South Tangerang

2. GITET Bekasi and PLTGU Tanjung Priok supply North Jakarta, Central Jakarta, and part of Bekasi
3. GITET Cawang and GITET Depok supply East Jakarta, Central Jakarta, and South Jakarta
4. GITET Cibinong supplies Bogor, Depok, and part of East Jakarta
5. GITET Kembangan supplies West Jakarta and part of Tangerang
6. GITET Depok supplies Depok and part of South Jakarta and part of Central Jakarta

In 2019, total electricity consumption in Jakarta reached 34,108 GWh, mainly coming from the household (41%) and business (37%) sectors, with an average increase of 2.3% in the last 5 years. In the same year, PLN served 4,583.7 thousands of customers with 92% of them being households (PLN, 2020). As of February 2021, Jakarta's peak load totals 4,493 MW (for day time) and 4,013 MW (for night time), 29-36% below the total available capacity of Jakarta at 6,340 MW (PLN UID Jakarta, 2021).

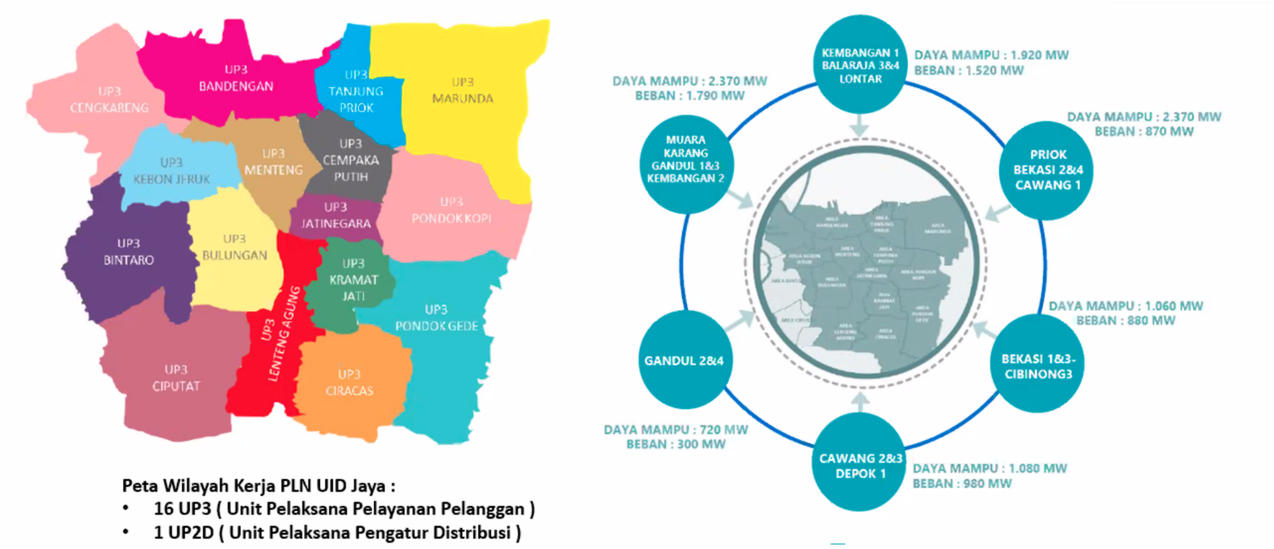


Figure 4. PLN UID Jakarta Raya's working area map (Greater Jakarta area) (Source: PLN UID Jakarta, 2021)

3. Methodology

Since the report aims to assess if the grid capacity in Greater Jakarta can provide charging needs for Transjakarta's e-bus fleet deployment, estimation on total maximum charging power demand and power peak load for all locations is performed. Figure 5 presents the methodology used in conducting the analysis.

For each location type, the assessment begins by plotting daily load curve and solar PV production curve. Daily load curve is plotted based on the information of charging scheduling time, charging power capacity, number of chargers, number of electric buses, and bus battery size. Subsequently, the daily load is used to calculate the total power needed to serve the charging demand. Meanwhile, the information of solar PV capacity, battery capacity, and hourly solar irradiation are used to plot the solar PV production curve. By having both curves, we can subtract the load with the available generated electricity from solar PV to estimate the power supplied by PLN's grid. Once the grid power requirement is obtained, total grid power demand for all locations can be calculated by scale up the demand's size based on total number of buses for all locations and bus battery capacity mix. The total grid power demand is then compared with the PLN's reserve capacity to determine the maximum charging power demand for all locations that can be served by PLN's grid.

By observing the daily charging load curve, we can determine the power peak load for each location. With the same peak load's time occurrence for each location type, charging peak load for all locations can be calculated by multiplying the peak load with total number of locations for each type. The peak load for all locations is then compared with PLN's daily supply curve to determine the maximum grid power peak load that can be served by PLN's grid.

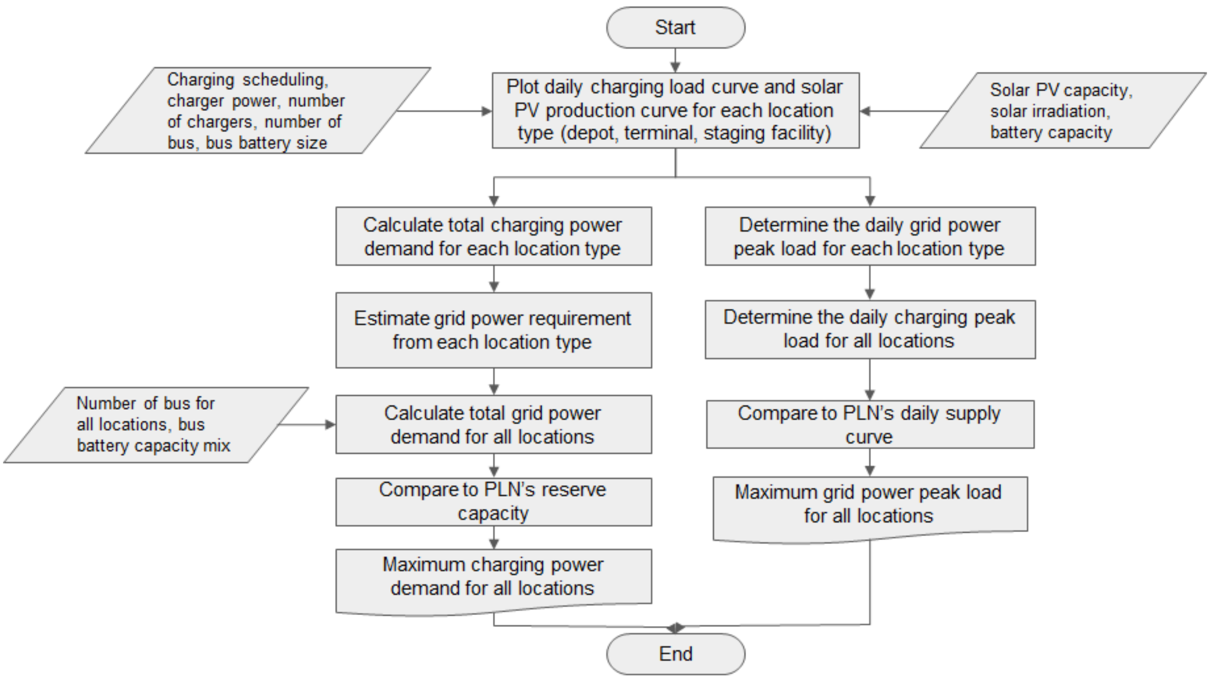


Figure 5. General methodology

4. Analysis of supply-demand balance of power

The supply and demand of electricity has to match in order for the charging system to work. Therefore, the total demand for electric bus charging needs to be determined first and later compared with the available power reserve of the grid serving Jakarta city. There are three different charging location types, which are depot, terminal and staging facility. Specific location has been chosen for each type to serve as a basis for total demand estimation. Therefore, there will be total demand for all depots, terminals and staging facilities that serve as charging locations separately. Local power distribution infrastructure is assessed to determine whether it can handle the additional load coming from each charging location. In this study, the supply constraint of the substations and cable connections will be analyzed for Depot Cijantung, Terminal Ragunan and Staging Facility Pejaten to give an example for the remaining charging locations.

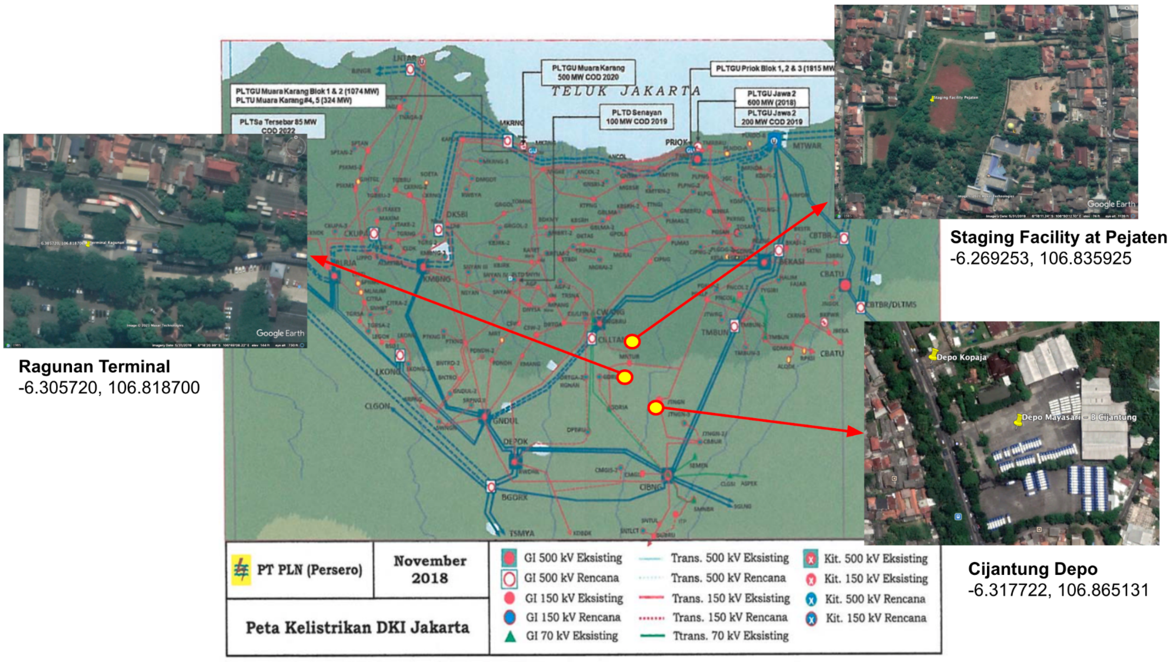


Figure 6. Location overview of selected charging location (depo, terminal and staging facility)

Depot charging

Depot Cijantung (-6.317722, 106.865131) is selected as a benchmark for the estimation of total charging demand of all depot locations.

The figure below shows the daily charging load curve along with the generation of 747 kWp of solar PV capacity. As can be seen from Figure 7, the charging for depot Cijantung occurs at night due to the overnight charging schedule applied for all depot locations. The daily average charging power load for this depot totals 4,392 kW. With 7 hours of daily operational hours, total electricity demand reaches 30,746 kWh/day. There are two peaks observed, both reaching 8,457 kW at 23.00 and 03.00, due to different schedules of electric buses arriving. It appears that the grid electricity purchases match the load of electric bus charging, meaning that the total load is served by PLN's grid. All of the solar PV production is sold to the grid during midday.

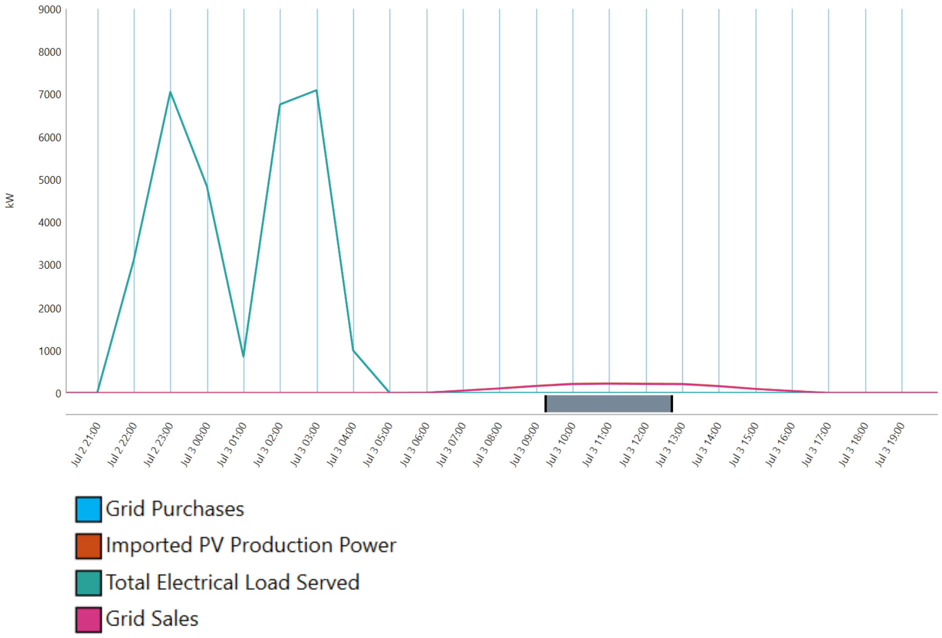


Figure 7. Load profile and power production for depot charging with 747 kW of solar PV capacity

With a slight variation of charging load throughout the year (see Figure 8), the average yearly consumption amounts to 11,222,346 kWh/year for depot charging.

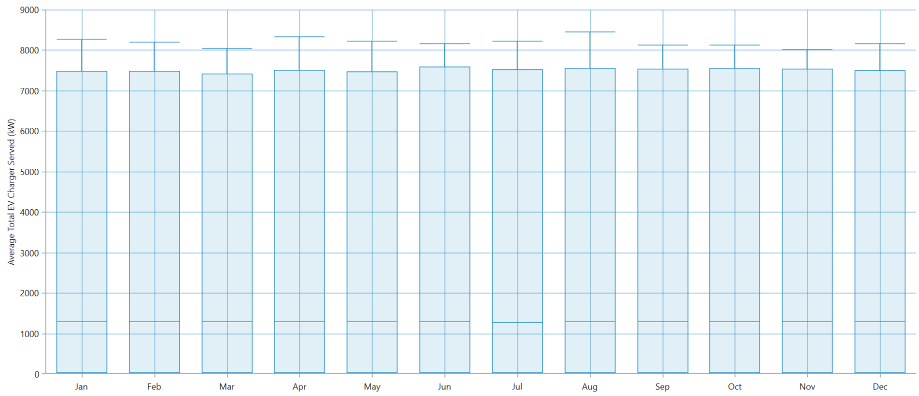


Figure 8. Load profile seasonality for depot charging

In practice, in order to receive the electricity supply from the grid, Depot Cijantung charging location will be connected to 20 kV medium-voltage network (JTM) from the nearest distribution substation, "*Gardu Induk*" Gandaria (see Figure 9). According to the PLN UID Jakarta, "*Gardu Induk*" Gandaria has two substation transformers with each of them serving a maximum load of 1,732 MVA. The average load served by these transformers are within 1,452-1,571 MVA. With minimum required installed power connections of Depot Cijantung is 9.40 MVA (after taking into account a power factor[1] of 0.9), the substation transformers would be far more than sufficient to meet the charging demand.

[1] Power factor (PF) of an AC electrical power system is defined as the ratio of the real power (i.e. the peak load, in Watt) absorbed by the load to the apparent power that is supplied to the circuit (i.e., the power connection to distribution unit, in VA). Typical power factor allowed by PLN ranges between 0.85–1.0 (1.0 is the most efficient).

Figure 9. Map of Depot Cijantung and “Gardu Induk” Gandaria

The charging power demand for Depot Cijantung is used to estimate the total power demand for all depot’s locations. There are 19 depot locations in total with each depot is assumed to provide charging for 200 electric buses. Since the assumed number of electric buses are similar in all depot locations, the estimation for total power demand is performed by multiplying the Depot Cijantung charging power demand with the total number of locations. Since the average charging power is 4.39 MW for a single depot, then the average daily power demand for all depot locations is 83.45 MW to generate 584.18 MWh/day. With the same charging scheduling, the peak load’s magnitude and time would be exactly the same for all depot’s locations. Therefore, summing up all 19 depot locations’ peak load gives us the total peak load of 160.68 MW.

Terminal charging

Terminal Ragunan (-6.305720, 106.818700) is selected as a benchmark for the estimation of total charging demand of all terminal locations.

The figure below shows the daily charging load curve along with the generation of 106 kWp of solar PV capacity. It can be seen from Figure 10 that charging at Terminal Ragunan occurs during day time, fully utilizing solar PV production. The daily average load for 20 electric buses charged hourly in the Terminal Ragunan is 262 kW with total electricity consumption of 2,098 kWh. With direct full utilization of solar PV production during midday, grid electricity purchases would be reduced 13% to 1,817 kWh/day. The peak load occurs for four hours from 10.00 - 13.00 at 300 kW, only 14.5% higher than the average load since the charging scheduling time is constant according to the continuously arriving electric buses on the terminal.

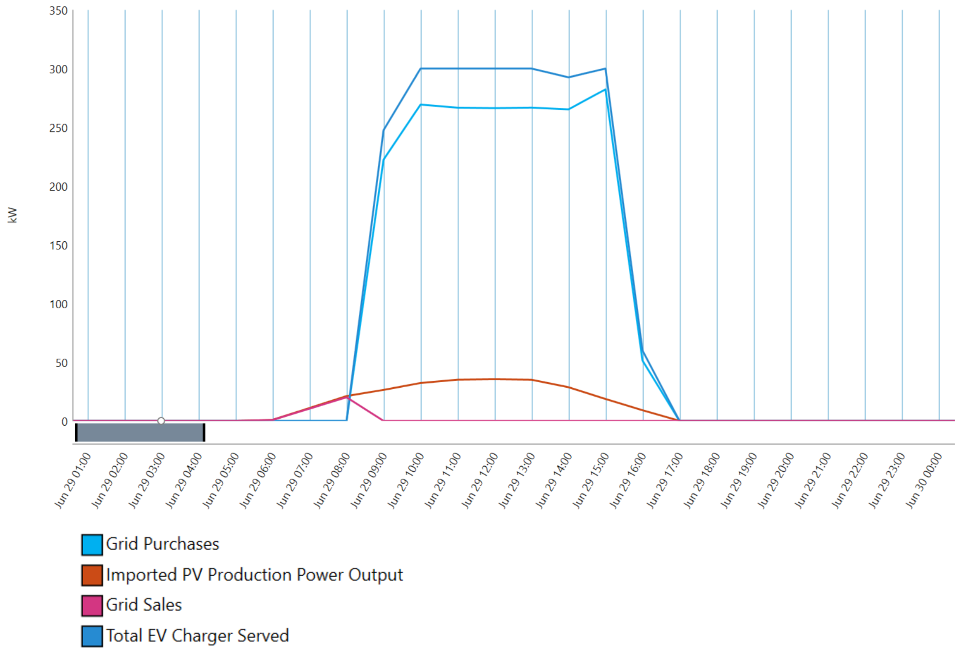


Figure 10. Load profile and power production for terminal charging with 106 kW solar PV and 1 MWh battery

Taking into account variation of charging load, the total demand for terminal charging is around 765,915 kWh/year. When 106 kWp of solar PV is integrated into the system, the total demand from PLN's grid is 663,254 kWh/year.

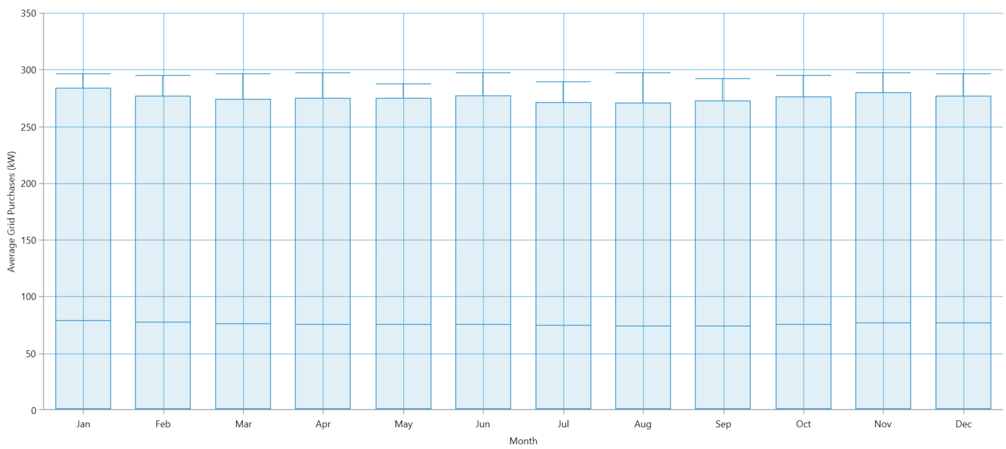


Figure 11. Load profile seasonality for terminal charging

Terminal Ragunan charging location will also be connected to 20 kV medium-voltage network (JTM) from the nearest distribution substation, which in this case is "*Gardu Induk*" Kemang (see Figure 12). According to the PLN UID Jakarta, "*Gardu Induk*" Kemang has three substation transformers with each of them serving a maximum load of 1,732 MVA. The average load served by these transformers are within 760-1,322 MVA. Since the peak load for Terminal Ragunan is merely 0.33 MVA (also after taking into account a power factor of 0.9, see previous footnote on 4.1 Depot Charging), the substation transformer is expected to have no difficulties in meeting the charging demand.

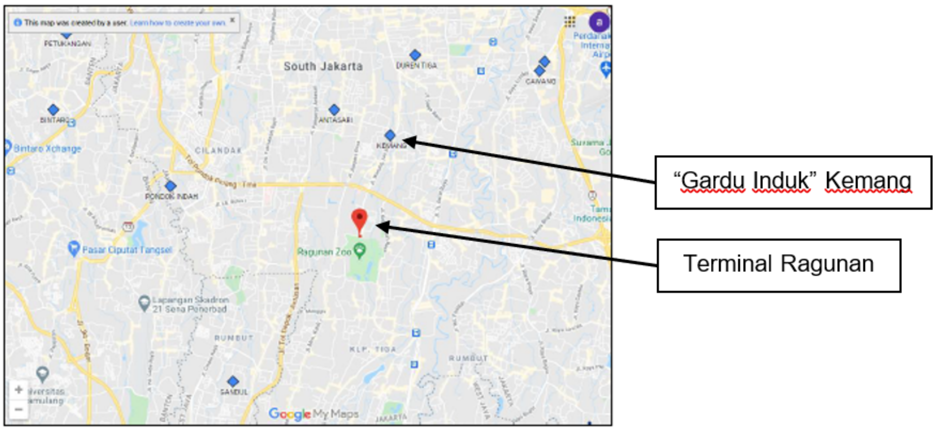


Figure 12. Map of Terminal Ragunan and "*Gardu Induk*" Kemang

The charging power demand for Terminal Ragunan is used to estimate the total power demand for all terminal locations. There are 12 terminal locations with a total of 210 electric buses arriving at the terminals each hour. By scaling up the power demand size of Terminal Ragunan according to the total number of electric buses, we obtain the total average power demand for all terminal locations of 2.75 MW. Without solar PV production, total electricity required from PLN's grid reaches 22.03 MWh/day. Meanwhile, utilization of solar PV generated electricity would lessen the grid electricity purchases to 19.08 MWh/day. With the same charging scheduling, the peak load's magnitude and time would be exactly similar for all terminal locations. Therefore, total peak load for all 12 terminal locations is estimated to be 3.6 MW.

Staging facility charging

Staging facility Pejaten (106.835924806,-6.269253200) is selected as a benchmark for the estimation of total charging demand of all staging facility locations.

The figure below shows the daily charging load curve along with the generation of 1.58 MWp of solar PV capacity. Figure 13 shows that charging at Staging Facility Pejaten also occurs during midday on off-peak hours (09.00 - 16.00), absorbing most of the solar PV production. However, the daily charging at staging facilities are divided into 3 batches with a total of around 4 hours and require 1,713 kW power demand on average. Without solar PV, Staging facility Pejaten would consume 8,565 kWh/day of electricity. Meanwhile, full utilization of solar PV would reduce grid electricity consumption by 37% to 5,387 kWh/day. The peak load is observed to be 4000 kW at 11.00.

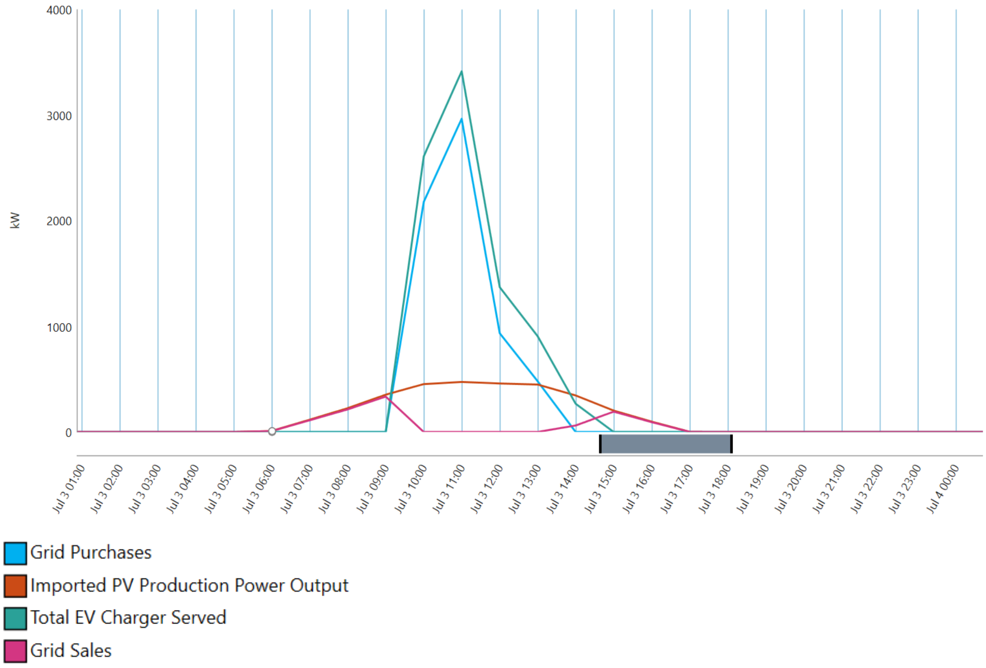


Figure 13. Load profile and power production for staging facility charging with 1,580 kW solar PV and 1 MWh battery

For a staging facility in the Pejaten area, the total power demand from the grid in a year is around 2,118,221 kWh/year, but when the solar PV is not installed in the location, then the total power demand will reach 3,126,225 kWh/year.

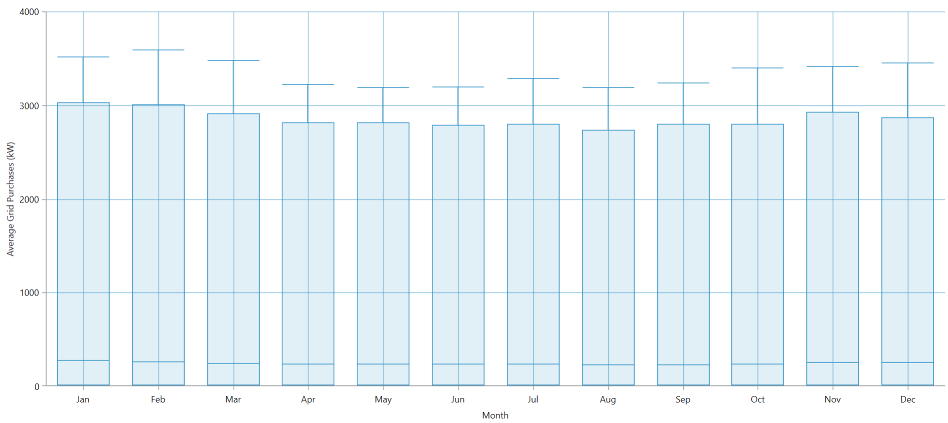


Figure 14. Load profile seasonality for staging facility charging

Similar to Terminal Ragunan, the staging facility in Pejaten area will likely be connected to 20 kV medium-voltage network (JTM) from "*Gardu Induk*" Kemang since it is the nearest distribution substation (see Figure 15). The minimum power connection required to meet charging demand in the staging facility Pejaten is 4.44 MVA (also after taking into account a power factor of 0.9, see previous footnote on 4.1 Depot Charging), or merely 0.23% from the substation transformer capacity.

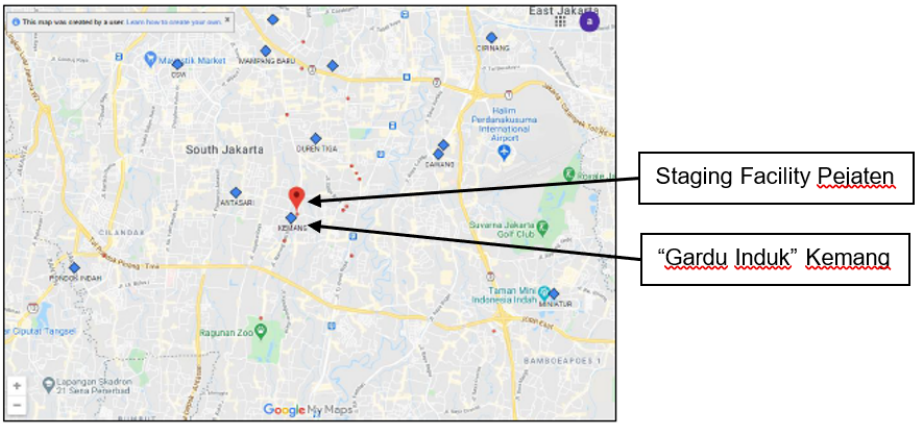


Figure 15. Map of Staging Facility Pejaten and "*Gardu Induk*" Kemang

Staging Facility Pejaten charging power demand will be used to estimate the total power demand for all staging facility locations. There are a total of 344 electric buses estimated to receive daily charging in four staging facility locations. Using this number, the charging demand size of staging facility Pejaten is scaled up to determine the total charging demand for all locations. The calculation results at 7.27 MW power demand and 36.37 MWh/day electricity demand from PLN's grid. However, if solar PV is utilized in the location, grid electricity purchases would reduce to 22.87 MWh/day. Besides, four staging facility charging locations will have 16 MW of total peak load.

Overall charging system

Compiling all the results above, depot charging constitutes the major portion of total charging power demand. From Depot Cijantung alone, total power demand is around 30.7 MWh/day, that is around 6 times the demand at Staging Facility Pejaten and 15 times the demand at Terminal Ragunan (see Table 1). Accordingly, the peak load also happens during depot charging at midnight (around 8.4 MW).

Table 1. Total charging demand for each charging location type

Charging location type	PV Capacity (kWp)	Average Power Demand (kW)	Electricity Demand (kWh/day)		Peak Load (kW)
			With PV	Without PV	
Depot Cijantung	747	4,392	30,746	30,746	8,457 (03.00; 23.00)
Terminal Ragunan	106	262	1,817	2,098	300 (10.00 - 15.00)
Staging facility Pejaten	1,580	1,713	5,387	8,565	4,000 (11.00)

For the overall system, taking into account all charging locations planned to be established, there will be a total of around 642.58 MWh/day of charging demand. As can be seen at Table 2, on average, the total average power demand will reach around 93.44 MW with peak load of around 160 MW that occurs at 02.00, 03.00 and 23.00 (when depot charging takes place).

Table 2. Total charging demand for all charging locations

Charging location type	Total number of location	Total number of bus	Power demand (MW)	Total Electricity Demand (MWh/day)		Peak load (MW)
				With PV	Without PV	
Depot	19	3,800	83.45	584.18	584.18	160.68 (02.00; 03.00; 23.00)
Terminal	12	210*	2.75	19.08	22.03	3.6 (10.00 - 15.00)
Staging facility	4	344	7.27	22.87	36.37	16 (11.00)
Total			93.44	626.13	642.58	160.68 (02.00; 03.00; 23.00)

Greater Jakarta in 2021 had a gap capacity of around 50%, that is 7,510 MW from the total average supply capacity of 13,895 MW. This margin of the power grid system means that it can serve the 93,44 MW of charging load well, since the load only contributes around 1.3% of margin capacity, indicating minimal impact on the grid.

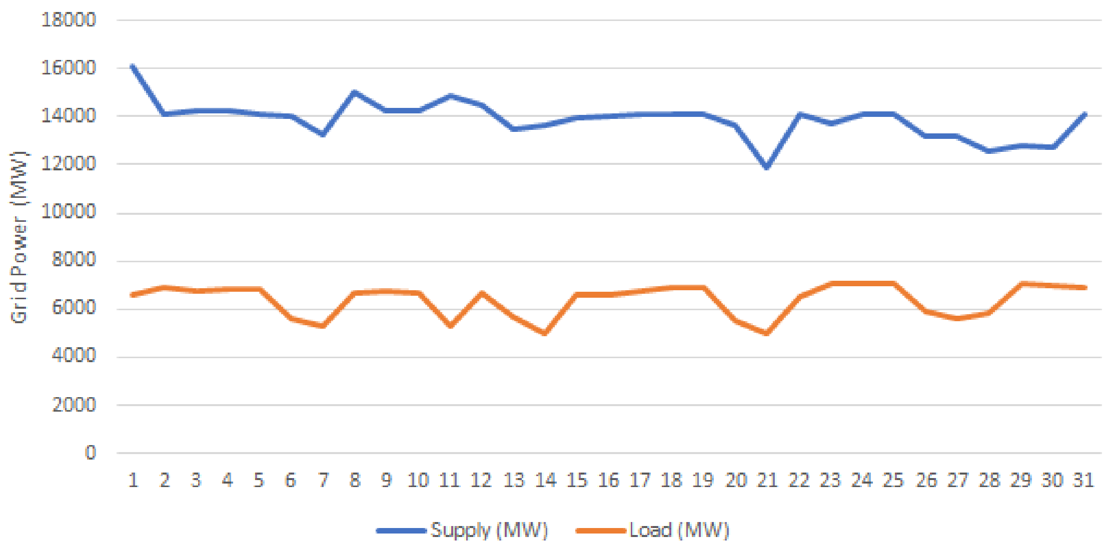


Figure 16. Supply and load curve of Jakarta recorded in March 2021

Furthermore, Jakarta's peak load was recorded at 4,493 MW in February 2021. This load occurs in the afternoon. Meanwhile, the charging power peak load comes in at 160.68 MW (around 3.5% of current peak load) that occurs during midnight, when the grid load is around 4,013 MW. The hours for charging electric buses in the bus depots is between 22.00 – 04.00, when power demand surplus occurs in the Java-Madura-Bali system, since the overall peak load occurs in the afternoon. Therefore, it can also be inferred that the charging peak load will not shift the overall peak load of the grid, and it does not create a significant burden to the grid.

5. Infrastructure needed to charge electric bus at different charging locations

In order to cater the electricity demand from electric buses charging, the required power distribution infrastructure must be considered. In Jakarta, this becomes a shared responsibility between PLN UID Jakarta (*distribution unit*) and the customer (facility owner). The facility owner must provide the required technical (and administrative) data related to the charging demand to PLN UID Jakarta (including bearing the installation and connection costs) and also has to ensure that the charging infrastructure meets operation-worthy certification (*sertifikat laik operasi*, "SLO") and the electric vehicle charging safety requirement as stipulated in the MEMR Regulation No. 13/2020 (Article 25). PLN UID Jakarta, on the other hand, must ensure the electrical connection, supply, grid stability, and overall safety within its electrical system authority.

In general, the required infrastructure will depend on the charging scenario and location in question. As discussed in Chapter 4, there are three types of charging scenarios and locations, namely the Depot, Terminal, and Staging Facility charging. According to PLN UID Jakarta, they will assist in determining whether it is required to build a new infrastructure (e.g. connecting to a new 20 kV cable or building a new distribution substation) or an upgrade (e.g. connecting to an existing infrastructure) would suffice from the technical data requirement (such as charging demand, geographic location, etc.) and site surveys.

Based on the demand analysis in Table 1 (Section 4.4), all three charging scenarios will require a medium-voltage connection since the required power (based on the peak load) is higher than 197 kVA (PLN UID Jakarta, personal communication, April 8, 2021). Therefore, it is likely that to meet the charging demand, a connection to the 20 kV medium-voltage network (JTM) is required. However, it is important to note that the specific required infrastructure will depend on the technical specification and geographic location of the demand. Overall, the minimum installed power connections are at least 9.40 MVA, 0.33 MVA, and 4.44 MVA for depot, terminal, and staging facility charging, respectively (based on the peak load presented in Table 1, after taking into account a power factor of 0.9, as discussed in Section 4).

In general, the required infrastructure includes a medium-voltage main distribution panel (MVDMP) and a low-voltage main distribution panel (LVMDP). MVMDP generally functions to receive and distribute power supply from PLN substations to the consumer side, while also acting as a control, protect, and isolate the electrical equipment. Since most EV chargers are in low-voltage (220–380 V), the voltage (20 kV) should be further stepped down using a transformer at the customer's side, therefore LVMDP is required to distribute power supply to the end-use electrical appliances, including chargers. Figure 17 represents the typical electrical installation for charging at depots.

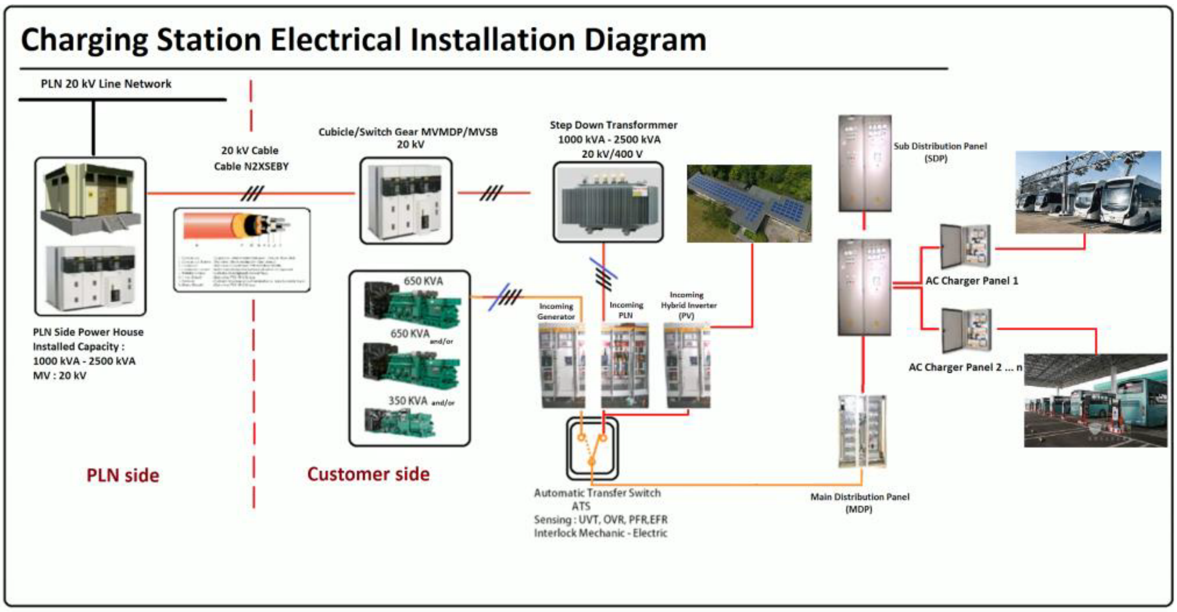


Figure 17. Graphical representation of electrical installation diagram at bus depot;
Adapted from (C40 CFF, 2021)

Depot

Charging at depots has the highest power demand, reaching 8.4 MW which will require at least a power connection of 9.40 MVA. As the required power is huge, existing depots will not likely have the existing installed power capacity to meet such demand. Therefore, to cater these demands building an MVMDP that connects to PLN's nearest distribution substation is required. Depending on the existing LVMDP at the depot, it might also need an upgrade to reduce the medium-voltage (20 kV) to low-voltage (220–380 V) for use.

Terminal

Terminal charging has the least required peak power capacity compared to the other two scenarios, that is 300 kW (~0.33 MVA). That said, to cater this power demand, a connection to medium-voltage is already required (power demand higher than 197 kVA already belongs to a medium-voltage customer group). Similar to Depot charging, building a new MVMDP at the Terminal Ragunan might be a prerequisite, assuming there is no existing MVMDP at the terminal.

Staging facility

Peak charging demand at the staging facility is the second largest between the three scenarios, giving as high as 4 MW (~ 4.44 MVA) required power connection. Also similar to charging at the depot, charging at the staging facility will likely require building an MVMDP and an LVMDP at the staging facility site to cater the charging demand.

In general, additional site surveys by PLN UID is required to know the specific requirements for the upgrades at all three locations.

6. Electric power connection cost assessment

Power connection to PLN's distribution grid for both new or existing (for an upgrade) customers is regulated under the MEMR Reg. No. 27/2017 regarding "Level of service quality and costs associated with the distribution of electricity by PT PLN (Persero)" as amended by MEMR Reg. No. 18/2019. In this section, total power connection costs for each charging location/scenario will be discussed in more detail.

MEMR 27/2017 stipulated that consumers have to file an application to the local PLN distribution unit to request a power connection (or an upgrade) and will be charged a connection fee ("*biaya penyambungan*"). Normally, consumers can choose between a regular electric power connection tariff (post-paid) or a pre-paid one. In addition, MEMR 27/2017 also subject consumers to a subscription guarantee fee ("*jaminan langganan tenaga listrik*", "UJL") that is set at 1 month of the national average of electricity bill (given the corresponding tariff class) which should be paid at least 1 month after the power connection. In addition to the two costs, new power connections might also be subject to operation-worthy certification fees ("*biaya sertifikasi laik operasi*", otherwise locally known as "SLO"), which is normally paid to a separate third-party provider.

According to the MEMR 27/2017 (Appendix 1), the connection fee for a three-phase medium-voltage (> 197 kVA) connection is IDR 631/VA. Therefore giving the values as presented in Table 3. Subscription guarantee fee is calculated based on PLN's rate (https://web.pln.co.id/pelanggan/uang-jaminan-langganan), in this case, all three charging location is considered to have a B-3 (> 200 kVA) tariff class, giving a rate of IDR 200/VA. Lastly, SLO certification fee is calculated based on the maximum price set in the Appendix 3 of the MEMR 27/2017. According to the regulation, the maximum inspection and testing fee for a medium-voltage electric power installation is IDR 4,000,000 (for transformers with capacity between 200 kVA and 600 kVA) and IDR 7,000,000 (for transformers with capacity between 2.5 MVA and 3 MVA). An indicative total connection costs for the three scenarios is presented in Table 3.

Table 3. Estimated power connection cost to PLN's distribution grid for each charging location/scenario

	Depo (Cijantung)	Terminal (Ragunan)	Staging (Pejaten)
Power connection (MVA)	9.40	0.33	4.44
Connection fee (IDR)	5,929,296,666	210,333,333	2,804,444,444
Subscription guarantee fee (IDR)	1,879,333,333	66,666,666	888,888,888
SLO certification fee (IDR)	7,000,000	4,000,000	7,000,000
Total estimated cost (IDR)	7,815,629,999	280,999,999	3,700,333,332

Note: Costs are based on MEMR 27/2017 (Appendix 1 for connection fee and Appendix 3 for SLO fee) and PLN's subscription guarantee fee (https://web.pln.co.id/pelanggan/uang-jaminan-langganan). Additional costs might still be incurred from unforeseen expenses and variable costs from connection site visits by PLN and SLO certification by a certification body.

In addition, by scaling up the estimated connection costs for the overall charging system for Transjakarta's e-bus fleet deployment (Table 2) linearly (i.e., the power connection required is assumed to be the same), the total estimated connection cost would amount to a total of 166.67 billion IDR, which is broken down into: 19 bus depots (a total of 148.5 billion IDR), 12 terminals (a total of 3.37 billion IDR), and four staging facilities (a total of 14.8 billion IDR).

7. Conclusion

Based on the previous analysis and study, there are several key takeaways:

1. The total charging power demand for all charging locations is 93.44 MW. Therefore, it can still be served by PLN's grid since it contributes to merely 1.3% from the overall grid's reserve capacity.

2. With solar PV utilization, the total electricity demand for all locations is 626.13 MWh. By relying only on the grid, the total electricity demand will increase by 2.6% to 642.58 MWh/day. Nevertheless, both demand can be served well by PLN's grid since it represents less than 0.5% from the grid's reserve capacity (180.24 GWh/day).

3. The charging power peak load occurs during midnight at 160.68 MW. This represents only 3.5% of current Jakarta's peak load. It does not create a significant impact to the grid.

4. Determination on which distribution substation needs to be connected to each charging location depends on proximity to the charging location and adequacy of reserve capacity. For Depot Cijantung, it will be connected to the Gandaria distribution substation. Meanwhile, Terminal Ragunan and Staging Facility Pejaten will be served by Kemang distribution substation. Other charging locations would need to be assessed further, to determine the appropriate distribution substitution to be connected to.

5. Based on the charging demand analysis, a connection to a 20 kV medium-voltage network (JTM) is required to cater the electricity demands at the three charging locations, since all three charging scenario's power demands are higher than 197 kVA. Depot charging peak demand is the highest at 8.5 MW, while Terminal charging and Staging Facility charging peak demand reach 0.3 MW and 4.0 MW, respectively. Taking into account a power factor of 0.9, the minimum required power connection for each charging scenario is 9.40, 0.33, and 4.44 MVA, respectively.

6. The required infrastructure to cater the electric bus charging demands on each charging scenario will generally include building a medium-voltage main distribution panel (MVMDP) on the customer side and building (or upgrading) a low-voltage main distribution panel (LVMDP) to distribute power supply to the EV chargers. For Depot Cijantung, it is very likely to build a new MVMDP at the site since the peak demand is very high (8.5 MW). For Terminal Ragunan, a connection to an existing 20 kV cable from PLN substation might suffice as the peak demand is relatively low. Meanwhile, Staging Facility will require building a new MVMDP and LVMDP since the location is new.

7. Overall, the required power connection costs (i.e., connection fee, subscription guarantee fee, and SLO certification fee) for Depot Cijantung is the highest given its peak demand, amounting to IDR 7.8 billion. Meanwhile, Staging Facility Pejaten and

Terminal Ragunan connection costs are estimated at IDR 3.7 billion and IDR 281 million respectively.

8. References

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