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Study on Power System of EV Bus Depot Charging System and Prospect for Smart Charging Implementation

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Abstract: The regional government of Jakarta, has operated 52 units of electric buses with a battery capacity of 324 kWh, as part of an effort to reduce CO_2 emissions from the transportation sector. The number of electric buses will continue to increase to 14,136 units in 2030. Electric bus operators built 15 units of charging stations (CS) with a capacity of 200 kW with CCS-2 plugs. The electrical power for the charging station is supplied from 4 units of transformers with a capacity of 1.25 MVA. Buses are charged alternately from 10 pm until around 03 - 04 am. From the results of power quality measurements for 1 week with 1 minute intervals, on the medium voltage side, it appears that the power factor is good (> 0.9) when the CS is operated, but when idle between 04 am – 09 pm, the power factor drops to 0.2 - 0.3 because the system only supplies transformers with an empty load. As a result of this operation, operators are subject to fines for excess kVArh. However the voltage fluctuations is still normal, with the voltage moves between the upper and lower limits of the medium voltage standard, (SNI 04-0227-2003).This paper evaluates the electrical system in this electric bus depot, power quality measurements and several inputs for system improvement including initial studies for smart charging implementation.

Keywords: EV Bus fleet charging; Charging Profile; Smart Charging; Charging Infrastructure

1 Introduction

1.1 Background

In line with the increasing awareness of the world community about the effects of greenhouse gases, countries in the world are trying to reduce carbon emissions from various sectors[1–3]. In energy sector, many approaches to get eco-friendly energy solutions by means of state-of-the-art energy harvesting technology such as more efficient solar cells, piezoelectric and electromagnetic generators.[4,5] Using energy resources wisely by getting the advantage from intelligent and sustainable manufacturing can lead to less carbon emission for each product.[6] However, even though the manufacturing process has produced less carbon for each product, the waste contained with hazardous material such as e-waste still needs to be paid attention to. Collaborative action from government, industry stakeholders and society for better waste management is very necessary.[7] Reducing carbon emission in the transportation sector, it can be seen that the number of electric motorized vehicles (electric vehicles) has increased significantly. This is because several countries have issued policies that support the acceleration of electric vehicle (EV) adoption, including policies limiting Internal Combustion Engine (ICE) vehicles, providing incentives such as reduced purchase taxes, and adequate infrastructure.[8,9]

Currently, almost all automotive manufacturers have EV products or are preparing their EV products. Many non-automotive companies have also entered the EV business, for example: Huawei, Xiaomi, Samsung and Sony. Likewise in Indonesia, the number of EVs is expected to continue to increase along with increasingly competitive EV prices. Along with the increasing number, large number EV unavoidably may have impact to grid. Incoordination of higher penetration of EVs and photovoltaic systems can lead to increased harmonics and voltage unbalances in power network.[10] The connections of multiple EVs, particularly in fast charging context, can significantly impact network voltage levels, pushing them beyond safe operational threshold[11] Uncontrolled EVs charging in residential during peak period can lead to higher energy demands and potential issues with power quality and stability.[12,13] Therefore, EV supporting infrastructure in the form of electric vehicle charging stations must be well prepared in order to increase the interest of both the general public and shared-car fleets such as Blue-bird, Go-car and Grab-car to switch to EVs.[14]

With the increasing number of charging stations (CS), the possibility of affecting the stability of the electricity network (grid) when CS are used, especially during peak loads, needs to be monitored. Public Smart Charging Stations increasing number as increasing number of EV adoptions serving as an interim solution before network reinforcements.[15] There are several ways to promote smart charging to consumers Distributor System Operator (in Indonesian case , Perusahaan Listrik Negara (PLN-National Electricity Company) can do some tariffs and fees special calculation (dynamic pricing).[16]

Therefore, this research will conduct a study on smart charging designs of public bus fleet that can be controlled to avoid disturbing the stability of the grid and can even be used to compensate for power fluctuations on the grid when needed.

1.2 EV BUS Electrification Policy

Electric-based vehicles are an embodiment of reducing carbon emissions in accordance with Indonesian law. Based on presidential regulation Perpres No. 55 Th. 2019 concerning the Acceleration of the Battery-Based Electric Motor Vehicle Program for Road Transportation[17]. In alignment with this presidential regulation, instruction on the use of electric vehicles (EVs) for operational purposes by government employees was also issued in 2022[18] .To make more meaningful impact, the government is currently accelerating the implementation of the use of electric vehicles, particularly electric buses for public transportation. The government's policy aims to change the use of fuel oil to natural gas and electricity due to the potential for air pollution by greenhouse gases, specifically carbon dioxide (CO_2) that produced by conventional vehicles. Globally, the transportation sector is the second largest contributor to emissions after electricity generation. In consequence, the government has committed in the Nationally Determined Contribution, to reduce greenhouse gas emissions by 29% to 41% by 2030 with a target of achieving Net Zero Emissions in 2060, this carried out to build national, regional, and community resilience from various risks of climate change. According to research conducted by Emprecha et.al, the utilization of EV buses reduces carbon emissions by 4.53 tons per year per bus[19]. Considering the urgency, the development of electricity-based vehicle infrastructure must be implemented immediately, namely a charging station system that can support electric bus operations.

Jakarta is one of the first cities in Indonesia that take action in public transportation sector. As a commitment to reduce pollution in the capital city, currently the Jakarta Provincial Government has operated 52 electric buses as a mode of public transportation named TransJakarta. The utilization of electric bus is planned gradually increased year by year. Based on the master plan, there will be an increase of up to 14,000 electric buses by 2030, replacing conventional buses. Figure 1 shows the masterplan for the bus electrification. This plan is made to reduce city's carbon footprint and improve air quality. Moreover, transition to electric buses is expected to support government goal to achieve green economy.

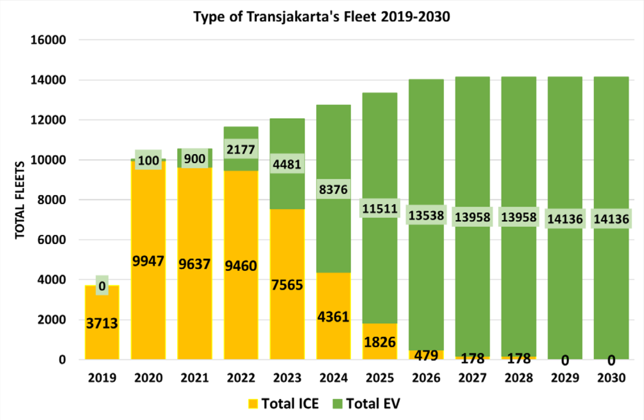

Fig. 1. EV Bus masterplan

Fig. 2. EV Bus Fleet BYD K9

In this initial operation, the bus operator, select BYD K9 from the K-series electric buses line up. Figure 2 shows the EV bus fleet inside the shelter, This electric bus has an acceleration power of up to 200 hp and a battery capacity of 324 kWh which is estimated to be able to reach 253 km. For charging the battery, the operator installed 15 units ultra-fast charging station 200 kW with CCS-2 plug (double gun).

1.3 Smart Charging

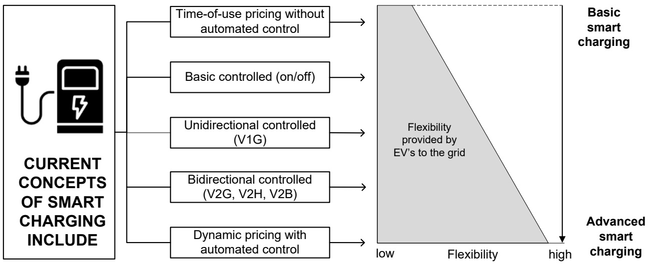

Fig. 3. Smart charging concept [10]

With Smart Charging, an EV's charging and discharging process is managed based on the driver's preferences as well as the state of the electrical grid (renewable energy availability)[20], this concept depict in Fig. 3 The following will be impacted by the significance of smart charging such as enhanced electrical transportation through effective charging procedures, efficient allocation of sustainable energy, and flexibility in preserving the equilibrium and robustness of the electrical grid. From study by Zhang et.al., their (smart charging) charging scheduling algorithm considering V2G and reactive power can optimize charging by reducing peak load, minimizing electricity cost and decreasing power factor penalties.[21]**)** From study by Debb et.al the peak demand even up to 50%. Smart charging also can increase penetration of renewable energy allowing to be charged during high renewable generation.[22] Nonetheless, innovation in EV Charging hardware give high possibility to boost EV penetration.[23]

Controlling increasing number of EV charging, there are several studies and researches discuss about scheduling algorithm. Shao et.al proposed framework offers advantages in convergence quality and computational efficiency.[24] With a cooperative-hierarchical multi-agent system proposed by Sabner et.al, the simulation conclude their system may significantly improve coordinating multiple EV CSs, reducing operational cost and preserving data privacy.[25] Another hierarchical control also proposed by Shao et.al, the result of the simulation is the control algorithm can reduce generation cost.[24] Other scheduling studies resulting in reduce charging delay and cost,[26] keep the voltage levels within standard[27] get more operation and maintenance of vehicle.[28–30]

Other than scheduling, several studies also discuss about optimizing smart charging – smart grid system infrastructure by coordination of DSO/TSO and transportation network[31,32] and optimizing on placement of public smart charging infrastructure.[33]**.**

In modelling smart charging infrastructure, there is a generic EV charging modelling by Heider et.al. [34]**.** While Bose and Sivraj make a model of smart charging infrastructure that employ IMCC to manage efficient charging process[35].

With the help of smart charging, electric vehicles (EVs) can now transfer their stored energy back to the vehicle's battery while maintaining its integrity. Hafez et.al state that modeled integrating EV charging station as smart loads for demand response provisions in distribution system resulting reduce peak loads, balance grid demand-supply and improve efficiency.[36] In Europe, Van der Kam et.al stated with unified roaming protocols, smart grid functionality can be enhanced by allowing more efficient management of EV Charging**.**[37] Digital data interchange (vehicle charging status, feasible charging speed, time when the e-driver wishes to leave, and minimum battery charge level) is necessary for the Smart Charging chain to function[38].

2 Methodology

This study was carried out by collecting data directly through measurements, secondary data collection from utilities, observations and interviews with bus crew. Electrical measurements are not only used to determine energy consumption, but also look at the power quality aspect, considering that CS's main component is a rectifier and operates intermittently. To characterize the system's performance in respect to various power quality changes, multiple types of analysis are required.[39,40]

Significant advancements in monitoring technology that may be utilized to define disturbances and changes in power quality have been brought about by the growing concern for power quality. The power system experiences millisecond-long disruptions, which are more noticeable to equipment due to its heightened sensitivity, and the increased number of devices linked to the power systems can lead to power quality issues. These factors make it often essential to keep an eye on system functioning and assess the potential effects of disruptions[41].

2.1 Measurement

In this study, electrical power measurements were conducted using a Clamp-on Power Logger measuring instrument, the HIOKI PW3360-21. This tool is capable of measuring and recording electrical power parameters, employing multi-channel clamp sensors on single-phase to three-phase lines, which are typically used to aid energy audits and validate measurements in the energy-saving process. In Figure 4 the measurement process, data was retrieved from the outgoing control panel on the Medium Voltage side of the bus depot electrical system through the provided Test Block. The data recording process lasted for 7 days to discern the charging load patterns of electric buses on weekdays and weekends.

The measurement focused on parameters such as power, power factor, energy consumption and voltage. Those parameters will be plotted for further analysis. The power parameter is measured daily and will be presented in daily and weekly graphs. Power factor which is also an important parameter, will be presented on both daily and weekly graphs. This data will be displayed alongside power data plot to ease the analytical process. Energy consumption measured and will be resume in daily and presented in kWh unit.

Fig. 4. Measurement at PCC

2.2 Charging Station and Bus Operation Patterns

The operation pattern for 15 charging stations @ 200 kW to serve the charging of 52 electric buses with a battery capacity of 328 kWh is as follows:

- Charging is initiated at night, starting around 10 pm, in accordance with the buses' return to the depot.
- Buses will be charged in order of arrival and readiness for the charging
- Charging time for each bus is approximately 1.5 - 2 hours
- All buses are finished charging at approximately 3-4 am
- The bus departs from the depot to follow one of the four routes. Figure 5 shows the basic bus operation flow.

From interviews with the crew, we obtained information that one of the concerns in carrying out this operating pattern is to avoid fines from route owners in the event of delays in sending buses to bus stops.

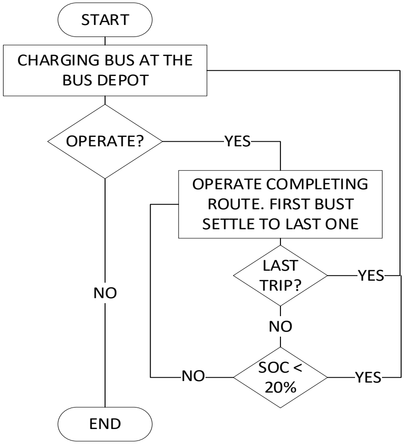

Fig. 5. Flow of Bus Operation

2.3 Electrical System Configuration

Figure 6 is a representation of the electrical single-line diagram for the depot bus's EV chargers. The system consists of four medium voltage transformers rated at 1.25 MVA. This power distribution system is supplied by the utility company with a 4.3 MVA power contract. The current system can provide power up to fifteen 200 kW EV chargers simultaneously. Extensive power system studies are needed to ensure that the specified electrical system satisfies the strict design specifications.

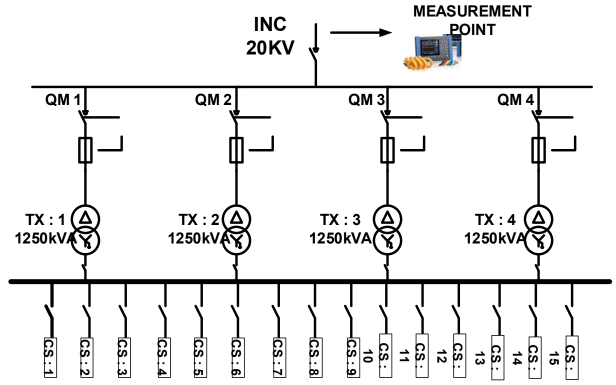

Fig. 6. Simplified Electrical Single Diagram

3 Result and discussion

The measurement was conducted over one week (1 minute interval) at medium voltage incoming terminal. The secondary data from the utility was also analyzed.

3.1 Power

Figure 7 and Figure 8, show the daily and weekly power profile respectively. The daily power profile, depicted from the weekly power profile, almost the same pattern in each day. The charging process starts around 09.30 to 10 PM and ends around 03.00 to 03.30 am. The peak load recorded 2,7 MW. The graph illustrates two peaks, where the first peak is when all the CS are operating (the number of buses is 49, the number of chargers is 15, so there are 3 times when all the chargers operate almost simultaneously, in the last charging period only 4-5 buses are charged) and the second peak is when the remaining buses are charged. From the graph it can be seen that the CSs is started almost at the same time. This causes the load to increase from around 11:15 PM to 00:00 AM.

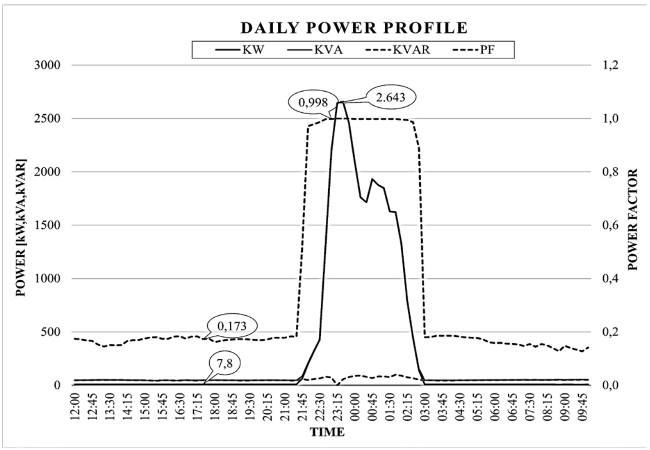

Fig. 7. Daily Power Profile

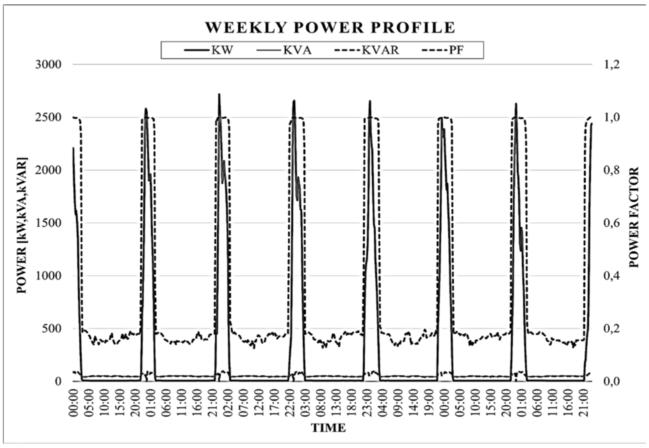

Fig. 8. Weekly Power Profile

3.2 Power factor

Figure 7 and Figure 8 show the power factor graphs, from which it is clear that when the CS is operating, the power factor is good, and when the CS is not operating, the power factor drops to 0.2. It is also evident from the graphs that the CS operates for approximately 5 hours and is idle for approximately 19 hours. The idle duration is much longer than the operating time duration. As a result, the maximum subscription power of 4.33 MVA is mainly used for no-load transformer loads (inductive loads). PLN sets the power factor of electricity customers at a minimum of 0.85 because if the power factor is less than 0.85, the reactive power needs (kVARh) will be supplied from the PLN grid by charging customers and subject to excess kVARh penalties.[42] Therefore, efforts must be made to reduce the supply of reactive power from PLN, namely installing capacitor banks. The capacity of the capacitor bank is calculated using Equations 1 to 3 [42,43]

$$P = \sqrt{3} \times V.I.\cos\varphi \qquad (1)$$

$$Q = \sqrt{3} \times V.I.\sin\varphi \qquad (2)$$

$$Qc = P(Tan\,\varphi\; existing - Tan\varphi\; Target) \qquad (3)$$

Where, P is active power (kW), Q is reactive power (kVAR), V is voltage (volt), I is current (ampere), cos φ is power factor and Qc is capacity of the capacitor.

In this case the power factor when the CS is idle will be increased from 0.2 as shown in Fig. 7 increased to 0.98. obtained the required capacity is 42.82 kVAR. Table 1. show the values of power factor correction.

Table 1. *Power Factor Correction*

Existing Apparent Power	45.09 kVA
Existing Reactive Power	44.41 kVAR
Proposed Apparent Power	7.96 kVA
Proposed Reactive Power	1.58 kVAR
Capacitance Power Required	42.82 kVAR

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3.3 Energy consumption

Based on measurements shown in Table 2. , the average daily energy consumption is 7.14 MWh, with the lowest is on Sunday 5.90 MWh and the highest is on Saturday 8.01 MWh. Since the total bus number is 52 units, the average energy stored per bus are 137 kWh, 113 and 154 kWh respectively.

Table 2. DAILY MEASUREMENT ENERGY

Date	Power	Min	Avg	Max	Energy (kWh)
Monday 08-May-23	kW	6,6	276,4	2581,8	6.642
	kVA	43,2	309,4	2582,4	
	kVAr	0,0	51,9	90,6	
Tuesday 09-May-23	kW	7,2	294,6	2718,6	7.074
	kVA	44,4	328,6	2718,6	
	kVAr	0,0	53,0	92,2	
Wednesday 10-May-23	kW	6,6	315,8	2658,0	7.584
	kVA	41,4	348,0	2658,6	
	kVAr	0,0	51,9	96,5	
Thursday 11-May-23	kW	6,6	285,0	2456,4	6.846
	kVA	43,8	317,6	2457,0	
	kVAr	43,0	53,5	98,7	
Friday 12-May-23	kW	6,6	330,1	2653,8	7.932
	kVA	40,8	361,8	2654,4	
	kVAr	39,9	52,9	94,5	
Saturday 13-May-23	kW	6,6	333,3	2628,6	8.004
	kVA	43,2	361,8	2628,6	
	kVAr	0,0	52,9	88,8	
Sunday 14-May-23	kW	6,6	245,2	2439,0	5.892
	kVA	41,4	277,9	2440,2	
	kVAr	40,3	53,2	91,5	
Average	kW	6,7	2997,2	2590,9	7.139
	kVA	42,6	329,7	2591,4	
	kVAr	17,6	52,6	93,2	

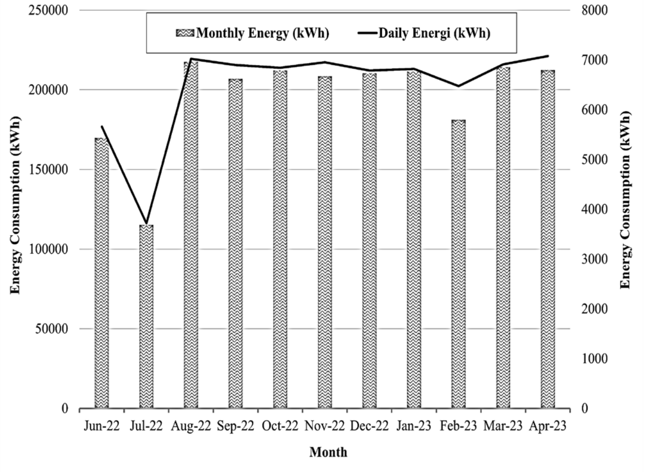

Fig. 9. Energy consumption

Figure 9 is obtained from the electricity bill of the electricity company (PLN) while the average daily energy consumption data is obtained by dividing the monthly energy consumption by the number of days in each month. from the electricity bill, the minimum monthly energy consumption was 115,271 kWh or 3,718.4 kWh per day, the maximum energy consumption is 217,593 kWh per month while the average monthly energy consumption is 196,338.9 kWh per month.

3.4 Voltage Profile

From the measurement data shown in Fig. 10 and Fig. 11, it can be observed that when the load is low, the voltage increases, and when the load is high, the voltage decreases. However, the movement of voltage fluctuations remains within normal range, with the voltage oscillating between the upper and lower limits of the medium voltage standard. With 15 CS units and the voltage supply system for CS, the system is secure, and there will be no voltage fluctuations exceeding the medium voltage standard limit. The standard voltage range, according to SNI 04-0227-2003, has a tolerance to the nominal voltage of +5% and -10%, so the minimum allowed voltage is 18,000 V and the maximum voltage is 21,000 V.

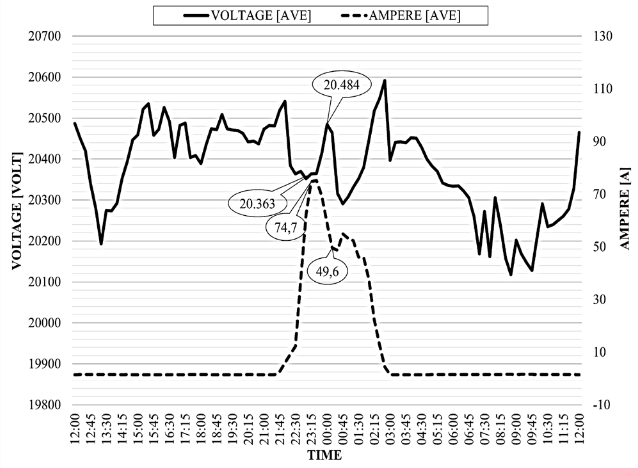

Fig. 10. Daily Voltage Profile

From the results of measurements and observations in the field, the Charging Station system in electric bus depots with conventional bus design and operating patterns will have the following impacts:

- Increased investment costs for procurement of transformers, cables, panels and installation work
- Un-controlled operating patterns, only based on the bus queue that enters first and charging according to the idle charger, resulting in excess kVArh fines because 2/3 of the time in a day, the system only supplies an empty transformer load.

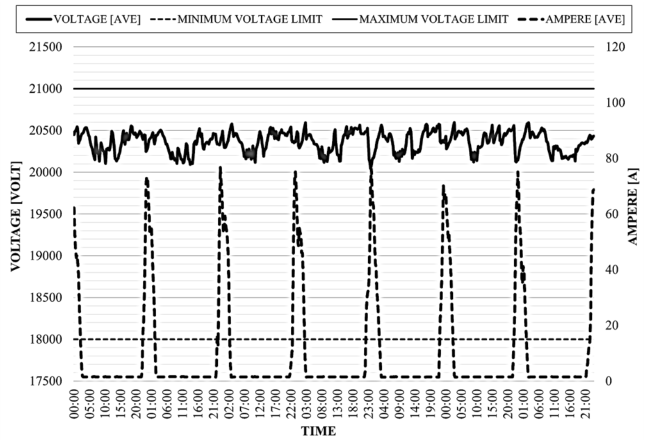

Fig. 11. Weekly voltage and current Profile

A broader smart charging scheme needs to be studied further, namely: a smart CS operational management system coupled with a smart fleet management system, starting from parking arrangements for charging, charging operations, arrangements for sending buses to the bus stops.

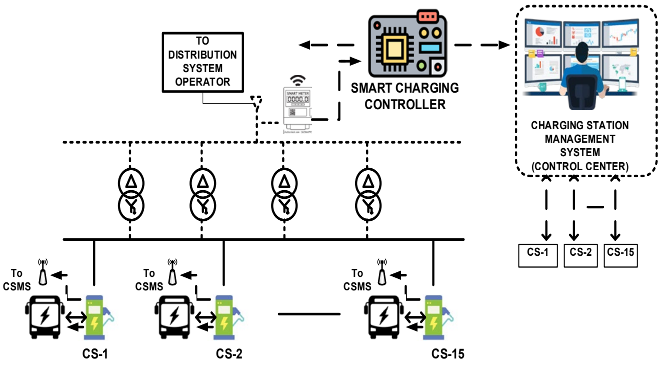

Fig. 12. Smart Charging Archtecture for EV Bus Depot

The proposed smart charging configuration is illustrated in Fig. 12. Smart charging is necessary not only to optimize charger operation by bus operators but also for utilities, enabling them to continually monitor the system's condition, particularly the feeder supplying the depot bus, and prevent feeder trips during intermittent CS operation.

The electrical power that can be used by CS is as described in equation (1), namely the contracted power with the utility minus the electrical power used by other facilities.

$$P_{availability} = P_{contract} - P_{others} - \sum P_{cs} \qquad (4)$$

and the maximum power that can be used by CSs is

$$P_{availability} > P_{request} \qquad (5)$$

Meanwhile, the total power when the CS is operating is the sum of the CS's electrical power currently in operation and the requested electrical power, which will be included in the operation.

$$\sum P_{cs} = \sum P_{cs} + P_{req} \qquad (6)$$

Figure 13 shows the flow chart of sequence/scheduling settings corresponding to the smart charging configuration depicted in Fig. 14. The master controller will monitor power availability, power used by other loads, and the accumulation of CS loads that will enter sequentially. As long as the available power remains sufficient, the CS-CS will enter sequentially. If the available power is insufficient, the next CS queue will be held until power becomes available or by reducing the power of the CS, thereby increasing the number of CS units that can be operated but with a longer charging duration due to the lower power.

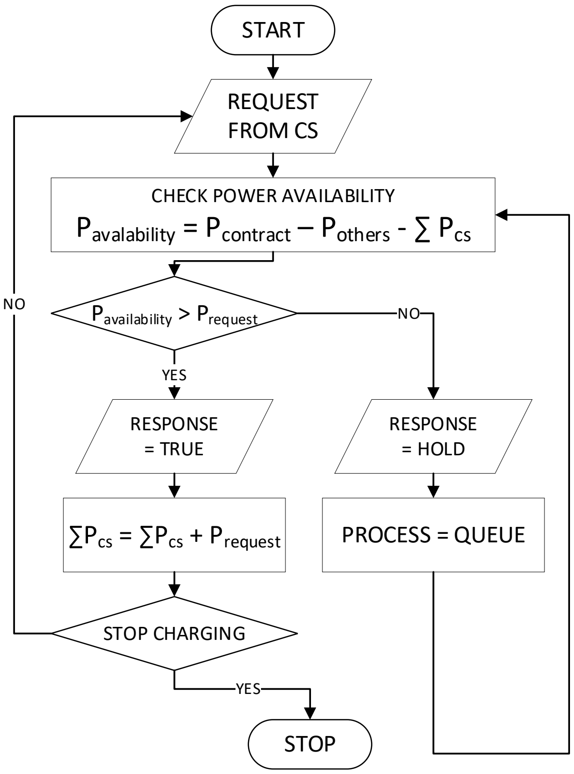

Fig. 13. Flow Chart of Smart Charging based on the proposed architecture

The smart charging architecture configuration consists of data acquisition system hardware, which retrieves existing power meter data to be sent to the Charging Station Management System (CSMS). The author and their team have developed CSMS[44] and have operated it for several years for CS operations. The data acquisition system has also been tested and functions well. The author also and their team also have conducted study on design of smart charging architecture for battery EV. The designed smart charging architecture proposed integrating CSMS with Electrical Power Monitoring System (EPMS) using IoT devices. This architecture offers a scalable and efficient way to manage EV charging, optimizing energy use and enhancing grid stability.[45] The next step is to apply a smart charging algorithm to optimize CS operation. The negotiation process for implementation at the bus depot is still ongoing.

4 Conclusion

With the operation of 15 cs (intermittent for each unit), the supply voltage is maintained in the range of 20.1 kV to 20.6 kV, still within the standard limits of 18.0 kV to 21.0 kV (SNI 04-0227-2003). This happens because the position of the distribution transformer is relatively not far from the substation and the network impedance is also not large. The CS load is also located only approximately 30 meters from the distribution transformer (transformer impedance 5.5 %).

To avoid kVArh penalties, this can be done by installing a capacitor bank or by setting the operation of the charging process. Installing bank capacitors will increase the investment burden. Resetting the charger operating pattern is a bit more troublesome for the depot staff but does not require investment.

In the future, the need for smart charging cannot be avoided with the increase in the number of EVs. Implementing smart charging will not only reduce the risk of a significant increase in peak load, but can also balance the load profile by filling valleys and reducing the sharpness of the load profile graph.

By rearrangement of bus charging procedures and regulating the flow of sending buses to routes, the buses can still be charged with electricity without needing to increase the number of CS. this will also improve the power factor

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