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RESEARCH ARTICLE

The Impact of a 1.1 MWp PV Rooftop Integration in Medium Voltage Distribution Networks

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Abstract

A high penetrating the capacity of Rooftop PLTS has an impact on the performance of distribution network operations and the prior technical studies only using simulation. This paper examines the impact of integrating a 1.1 MWp PV Rooftop into the medium voltage distribution network, involves a comparison between simulation data obtained using the ETAP software, before and after integration, compared with direct measurements. The results indicate improvements in the distribution operating performance. Following the integration, there was a 0.05% increase in voltage levels, a 0.06% increase in short circuit current, a 1.25% reduction in network losses, up to 8.9% harmonics current, up to 0.14% harmonics voltage, and a 0.28% decrease in power factor, as observed at both the substation and the network, they are in accordance with the measurement results

Keywords: pv rooftop, integration, medium voltage, operating performance

1. Introduction

1.1 Background and Scope

The growth of Rooftop PLTS which is integrated with the distribution network is increasing rapidly with an average monthly addition of 38 customers with an additional capacity of 328 kWp. In prior research [1] increasing penetration of Rooftop PLTS can affect the performance of distribution network operations including voltage levels, short circuit currents, power factor, network losses, and changes in THD [2]. To mitigate the impact, every application for a Rooftop PLTS integration permit must go through a technical review conducted by the network utility owner

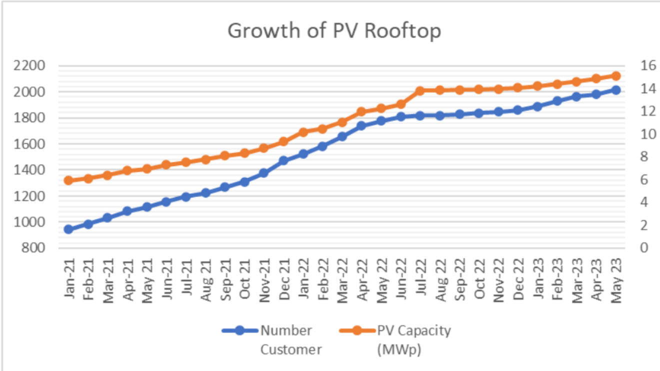

Figure 1. Growth of PV Rooftop in Jakarta

This research is to examine the integration of a 1.1 kWp Rooftop PLTS in a medium voltage distribution network impacted on the performance of distribution network operations such as voltage levels, power factor, short circuit current, network losses, harmonics current, and harmonic voltage, through simulation and measurement. An operational impact evaluation was carried out at the point of integration known as the Point of Common Coupling (PCC), namely at two substations that supply electricity to consumers, the KP 48 substation from the Satin feeder and the BK 66 substation from the Busana feeder. The two substations are connected to the Bekasi Substation. This configuration forms the Bekasi–Pondok Kelapa Subsystem, as depicted in Figure 2.

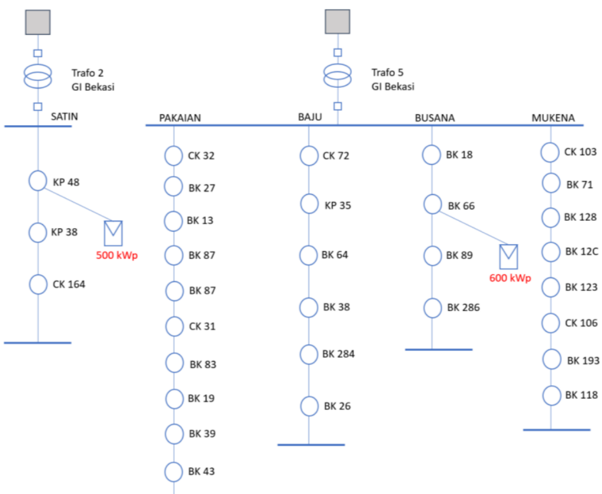

Figure 2. Medium Voltage Network In Pondok Kelapa Subsistem

1.2 Literature Review and Methodology

Many prior studies on the effect of PV Rooftop integration have been carried out the impact of voltage quality and network loss generated by distributed PV network connections and comparative distribution network operating performance analysis before and after connection to the PV network [3]. The voltage and losses impact has been shown in the formula below:

$$U_{node-M} = U_o + \Delta U_m \tag{1}$$

$$Loss_{node-M} = Loss_o + \Delta Loss_m \tag{2}$$

Where ΔU is voltage deviation, and $\Delta Loss_m$ is losses deviation, U_o, $Loss_o$ is voltage and losses before connected PV Rooftop, and m is number of node connected PV Rooftop.

There is a strong correlation between PV system and the harmonic performance of an existing network [4]. It shows that the solar panels system-generated disturbance and increased by 1.5 – 12.6% per 100 W/m2 for the harmonic disturbance frequency of 9 – 150 kHz [5]. Also, The losses network profile can be controlled through reactive power injection [6]. The standard limits stated in the grid code specify that the voltage should be within the range of –10 to +5 volts, and power factor should be greater than 0.85, Short circuit current should be below the breaking capacity of the equipment, THDv (Total Harmonic Distortion of voltage) should be less than 5%, and THDi (Total Harmonic Distortion of current) should be less than 3% [7].

2. Methodology

In the previous method that became a reference related to PV system design for the Primary Distribution System based on Loss and Voltage Drop Control Based on ETAP. Power flow is used to solve network power flow problems related to power balance of received and transmitted power. This paper applies a single line diagram to solve the PV connected load flow by using ETAP program using Newton-Raphson method. The result show that the primary power distribution system has a voltage drop of -0.04% that can reduce losses up to 3.67%, reduce reactive power loss by 5.08%. Meanwhile, the power loss is reduced to 5.06%. This can improve the efficiency of electric power[8].

We propose this Methodology to answer dan prove the change of All indicators by simulation using ETAP program as previous method and additionally with measurement. First, collecting the technical data such as the number substation of feeder, cable lenght and diameter, transformator capacity and percentage of loading. All the configuration single line diagram has been provided in masterdata and this research already uses the factual technical data.

For simulation, Software ETAP 19.01 is powerful to get all operating performance Indicators. Then we input All parameters to the Existing Drawing (Single Line Diagram) of one Sub-system in real data, with Day categorical Loading and Generating. Installing the Rooftop PV in BK 66 dan KP 48 with the specification as shown in table 1, then run 3 (three) simulations, (1) Loadflow Simulation, (2) Short Circuit Analysis Simulation, (3) Harmonic Simulation

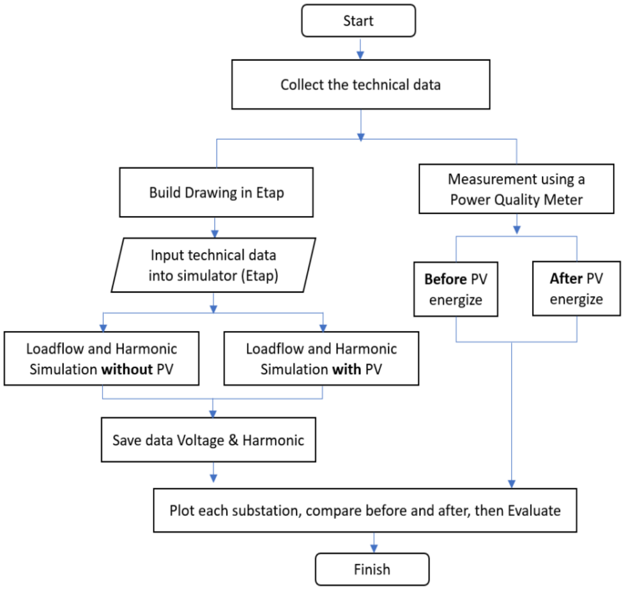

Figure 3. Methodology Flowchart

Table 1. Methodology Flowchart

Node (Substation)	BK 66		KP48	
	PV panel	Inverter	PV panel	Inverter
Merk	Longi	Huawei	Longi	Huawei
Type	LR5-72HPH-540	SUN200-100KTL	LR5-72HPH-540	SUN200-100KTL
Capacity	816.48 kWp	600 kW	689.04 kWp	500 kW

3. Result

3.1 Simulation Result

All simulations run with two scenarios, that is the result before installing the PV-Rooftop dan after energized. Then we save the complete result into ms. excell data. From the data, extracted several operating performance indicators like Voltage, power factor, and losses from loadflow simulation, a short circuit current from a Short Circuit Analysis Simulation, then THDv and THDi were simulated in The Harmonic Simulation. The Substation that nears form KP 48 dan BK 66 Substation Point of Common Couple (PCC) such us, KP 38, CK 164, BK 18, BK 89, BK 286, CK 32, BK 13, BK 39, BK 43, CK 72, KP 35, BK 284, BK 26, CK 103, BK 71, BK 193, BK 118.

3.1.1 Votage Level

As shown in (figure 3), the voltage level in PCC before (red colour dot) increased by about 0.05% after installing PV Rooftop (blue colour dot). The network voltage increased an average of 0.02% from before installed.

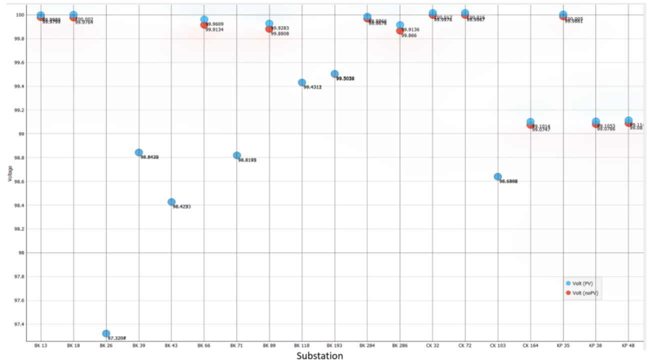

Figure 4. Plot before and after of a Voltage Level in percentage p.u

3.1.2 Power Factor

Decreasing about 0,28% level of PCC power factor before which red colour dot becomes blue colour dot, and according to average substations near PCC's power factor decreased about 1.13%, as seen in figure 4.

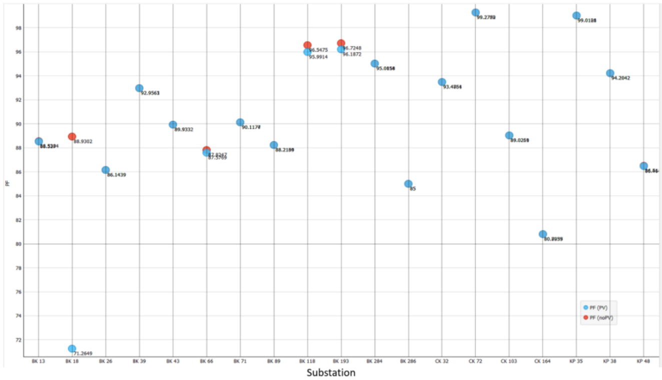

Figure 5. Plot before and after of a Power factor in percentage

3.1.3 Losses Network

Figure 5 shows that increase of 1.25% losses in PCC, and all network losses increase about 3.97% averaging all substation near PCC.

3.1.4 Short Circuit Current

The Increase of the Short circuit current Level should be considered in setting the relay parameter and MV panel breakdown. By seeing figure 6 shows that the increase in short circuit current (Isc) is only about 0.06 averaging at 0.19%.

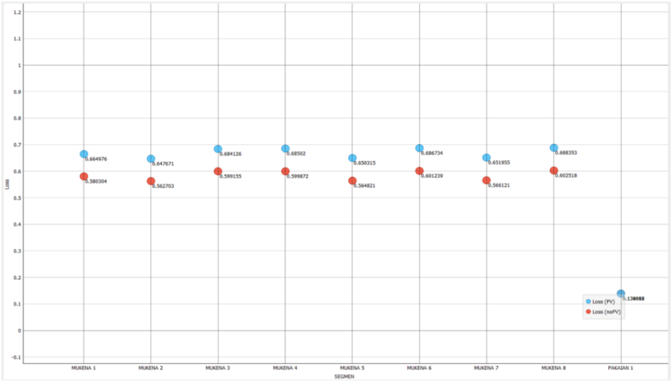

Figure 6. Plot before and after of a Losses Network in kW

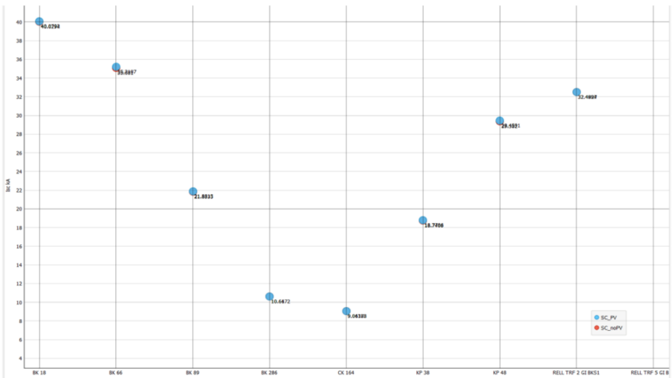

Figure 7. Plot before and after of a Short Circuit Curent Isc in kA

3.1.5 Harmonics

Raising from Zero level of harmonic before Installed becomes 0.141% level in THDv, and also 8,9% level in THDi. As an installed Inverter we use IEEE 18pulse1, with THD < standard IEEE. But when it operates in high penetration, then THD increases significantly. Raising form Zero level of harmonic before Installed becomes 0.141% level in THDv, and also 8,9% level in THDi which breaks standard limitation. As installed Inverter we use IEEE 18pulse1, with THD under standar IEEE. But when it operates in high penetration, then THD increase significantly. As seen in figure 8 and 9 the THDv and THDi rising to the level that impacted by Inverter's harmonic injection.

3.2 Measurement Result

A Comisioning and Measurement held in BK 66 Substation, Using Sonel PQM-711. By clamping the secondery CT of measurement when PV Rooftop in operation.

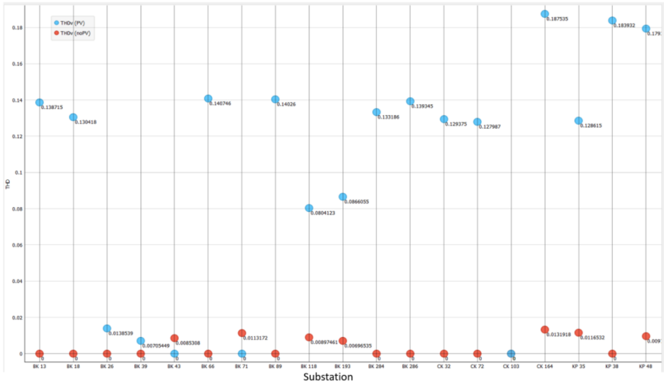

Figure 8. Plot before and after of THDv

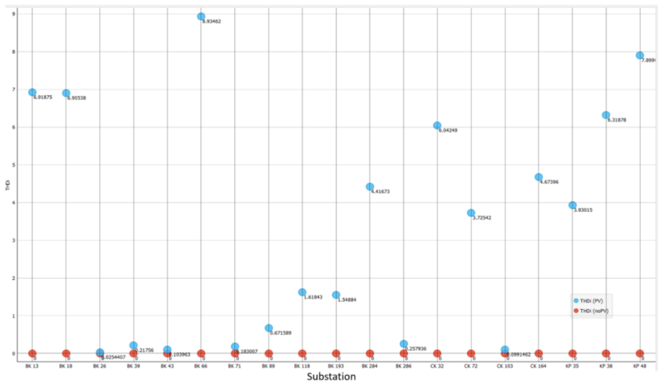

Figure 9. Plot before and after of THDi

Collecting data Instant then to be analyzed. As the result, can be resumed in table 2.

(a) (b) (c)

Figure 10. Measurement After PV Rooftop Energized (a) Voltage Level (b) Power factor (c) THDv and THDi

The voltage level increases from the per unit system, which is measured in the secondary and shows 59.6 volts, equivalent to 11.9 kV phase-to-neutral or 20.6 kV phase-to-phase, as illustrated in Figure 10(a). It exhibits a rise of 1% in voltage and a drop in power factor to 92.5%, as depicted in Figure 10(b). Additionally, Figure 10(c) presents the measurement of total harmonic distortion (THD) for current and voltage, showing an increase of 8.72% THDi and 1.647% THDv. This increase in THDi is due to the Inverter that uses a current source type model 18 Pulse VT.

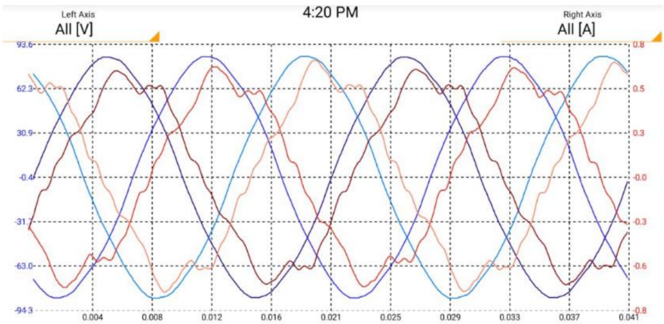

Figure 11. Profile of Voltage and Current waveforms

The current and voltage waveforms have been deformed due to the injection of harmonics from the Rooftop PV inverter equipment as shown in figure 11. Showing that the current waveforms is significantly deformed. By changing the wave curve to a furier series, to see the dominant N order harmonics. Figure 12 demonstrates the voltage and current waveform depicting the harmonic effects, with the harmonic order plot highlighting a significant rise in odd harmonics, particularly the 5th order. Finally, we will summarize our study findings based on the data presented in Table 2.

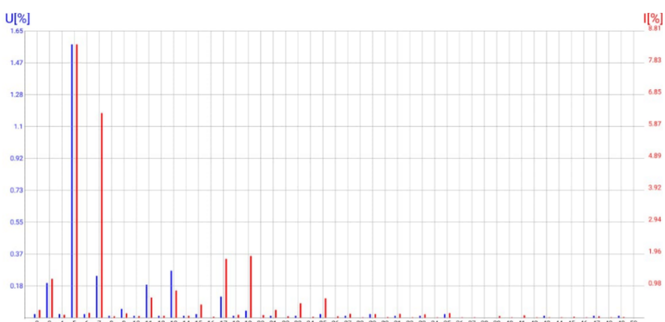

Figure 12. Measurement plot of voltage current form and Harmonic Orde-N

4. Conclusion

The conclusions of this study indicate that the integration of a 1.1 MWp PV Rooftop in a medium voltage distribution network has a significant impact on the operating performance. This integration results in an increase in voltage level of 0.05%, an

Table 2. Indicators pointed in BK 66 substation

Indicators	Standard Limit (gridcode)	Simulation		Measurement		Resume
		Without PV	With PV	Before PV	After PV	
Voltage Level	-10 < Un < 5 V	99.91	99.96	59,00	59,597	Increase
Power factor	0.85	87.82	87.58	95.1	92.5	Decrease
Losses (kW)	< 4 %	0.67	0.68	-	-	Increase
Isc (kA)	Break Capacity Isc Switchgear	46.0558	46.0846	-	-	Increase
THDv	5 %	0	0.141	1.41	1.671	Increase
THDi	3 %	0	8.93	6.84	8.72	Increase, Violance

increase in short circuit current of 0.06%, a decrease in network losses of 1.25%, current harmonics of up to 8.9%, voltage harmonics of up to 0.14%, and decrease in power factor by 0.28%. , both at the substation and in the network. Comparison between simulated and measured data shows a strong correlation. This research is part of a technical review to determine permits for integration of PV Rooftop by considering changes in operating performance indicators.

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Appendix 1. Result Simulation Table

a. Voltage Level Simulation

STATION	Volt (noPV)	Volt (PV)	PERCENTAGE
KP 48	99.09	99.11	0.03%
KP 38	99.08	99.11	0.03%
CK 164	99.07	99.10	0.03%
BK 18	99.98	100.00	0.03%
BK 66	99.91	99.96	0.05%
BK 89	99.88	99.93	0.05%
BK 286	99.87	99.91	0.05%
CK 32	100.00	100.02	0.02%
BK 13	99.98	100.00	0.02%
BK 39	98.84	98.84	0.00%
BK 43	98.43	98.43	0.00%
CK 72	100.00	100.02	0.02%
KP 35	99.99	100.01	0.02%
BK 284	99.97	99.99	0.02%
BK 26	97.32	97.32	0.00%
CK 103	98.64	98.64	0.00%
BK 71	98.82	98.82	0.00%
BK 193	99.50	99.51	0.00%
BK 118	99.43	99.43	0.00%
		average	0.02%

b. Power Factor

STATION	Volt (noPV)	Volt (PV)	PERCENTAGE
KP 48	86.51	86.46	-0.05%
KP 38	94.20	94.20	0.00%
CK 164	80.81	80.79	-0.02%
BK 18	88.93	71.26	-19.86%
BK 66	87.82	87.58	-0.28%
BK 89	88.21	88.22	0.00%
BK 286	85.00	85.00	0.00%
CK 32	93.49	93.48	-0.01%
BK 13	88.54	88.53	-0.01%
BK 39	92.96	92.96	0.00%
BK 43	89.93	89.93	0.00%
CK 72	99.28	99.28	0.00%
KP 35	99.01	99.01	0.00%
BK 284	95.01	95.01	-0.01%
BK 26	86.14	86.14	0.00%
CK 103	89.03	89.03	0.00%
BK 71	90.12	90.12	0.00%
BK 193	96.72	96.19	-0.56%
BK 118	96.55	95.99	-0.58%
		average	-1.13%

c. Losses Network

SEGMEN	Loss (noPV)	Loss (PV)	PERCENTAGE
SATIN 1	2.34	2.34	0.12%
SATIN 2	0.09	0.09	-0.08%
SATIN 3	0.04	0.04	0.18%
BUSANA 1	0.62	0.62	1.29%
BUSANA 2	0.67	0.68	1.25%
BUSANA 3	0.35	0.35	0.01%
BUSANA 4	0.33	0.33	0.01%
PAKAIAN 1	0.14	0.14	0.09%
PAKAIAN 2	0.16	0.16	0.08%
PAKAIAN 3	0.15	0.15	0.07%
PAKAIAN 4	0.12	0.12	0.08%
PAKAIAN 5	0.12	0.12	0.07%
PAKAIAN 6	0.15	0.15	0.05%
PAKAIAN 7	0.08	0.08	0.07%
PAKAIAN 8	0.11	0.11	0.05%
PAKAIAN 9	0.07	0.07	0.04%
PAKAIAN 10	0.04	0.04	0.04%
BAJU 1	0.03	0.03	0.30%
BAJU 2	0.01	0.01	1.15%
BAJU 3	0.04	0.04	0.15%
BAJU 4	0.04	0.04	0.12%
BAJU 5	0.00	0.00	1.15%
BAJU 6	0.04	0.04	0.07%
MUKENA 1	0.58	0.66	14.59%
MUKENA 2	0.56	0.65	15.10%
MUKENA 3	0.60	0.68	14.18%
MUKENA 4	0.60	0.69	14.19%
MUKENA 5	0.56	0.65	15.14%
MUKENA 6	0.60	0.69	14.22%
MUKENA 7	0.57	0.65	15.16%
MUKENA 8	0.60	0.69	14.25%
		average	3.97%

d. Short Circuit Current

GARDU	SC_noPV	SC_PV	PERCENTAGE
RELL TRF 2 GI BKS1	32.48269	32.49943	0.05%
KP 48	29.38205	29.45913	0.26%
KP 38	18.74083	18.77864	0.20%
CK 164	9.043728	9.061881	0.20%
RELL TRF 5 GI BKS	46.05578	46.08464	0.06%
BK 18	40.02937	40.07923	0.12%
BK 66	35.08099	35.21067	0.37%
BK 89	21.83351	21.88126	0.22%
BK 286	10.61722	10.64003	0.21%
		Average	0.19%

e. Total Harmonic Distortion

STATION	THDv (noPV)	THDv (PV)	THDi (noPV)	THDi (PV)
KP 48	0.010	0.179	0	7.899089
KP 38	0.000	0.184	0	6.318781
CK 164	0.013	0.188	0	4.673955
BK 18	0.000	0.130	0	6.905384
BK 66	0.000	0.141	0	8.934623
BK 89	0.000	0.140	0	0.671589
BK 286	0.000	0.139	0	0.257936
CK 32	0.000	0.129	0	6.042495
BK 13	0.000	0.139	0	6.918746
BK 39	0.000	0.007	0	0.21756
BK 43	0.009	0.000	0	0.103963
CK 72	0.000	0.128	0	3.725416
KP 35	0.012	0.129	0	3.930154
BK 284	0.000	0.133	0	4.416729
BK 26	0.000	0.014	0	0.025441
CK 103	0.000	0.000	0	0.099146
BK 71	0.011	0.000	0	0.183007
BK 193	0.007	0.087	0	1.548841
BK 118	0.009	0.080	0	1.618429

f. The Growth PV Rooftop in Jakarta

Bulan Pemakaian	Jumlah Pelanggan	TOTAL Daya PLTS MWp	Jumlah Pelanggan	TOTAL Daya PLTS MWp
Jan-21	945	5.92		
Feb-21	984	6.12	39	0.21
Mar-21	1,034	6.41	50	0.28
Apr-21	1,084	6.8	50	0.39
May 21	1,115	6.96	31	0.16
Jun-21	1,156	7.31	41	0.35
Jul-21	1,196	7.52	40	0.21
Aug 21	1,222	7.8	26	0.27
Sep-21	1,267	8.1	45	0.3
Oct 21	1,309	8.33	42	0.22
Nov-21	1,375	8.75	66	0.43
Dec 21	1,473	9.36	98	0.61
Jan-22	1,523	10.18	50	0.82
Feb-22	1,583	10.47	60	0.28
Mar-22	1,656	11.05	73	0.59
Apr-22	1,739	11.95	83	0.89
May 22	1,776	12.25	37	0.31
Jun-22	1,809	12.62	33	0.37
Jul-22	1,818	13.83	9	1.2
Aug 22	1,819	13.84	1	0.01
Sep-22	1,827	13.87	8	0.03
Oct 22	1,837	13.92	10	0.05
Nov-22	1,847	13.96	10	0.04
Dec 22	1,859	14.06	12	0.1
Jan-23	1,887	14.22	28	0.16
Feb-23	1,928	14.39	41	0.16
Mar-23	1,964	14.6	36	0.21
Apr-23	1,979	14.88	15	0.29
May 23	2,016	15.13	37	0.25
		Average	38	0.328