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Surface Maintenance Analysis of Module PV To Improve Solar PV Performance

Adrian Mansur*[1], Heri Sutanto[2], Jaka Windarta[3]
*[1]Magister 0f Energy, Diponegoro University, Semarang, Central Java, Indonesia
adrianmansur@students.undip.ac.id[1]
[2]Faculty of Science and Mathematics, Diponegoro University, Semarang, Central Java, Indonesia
[3]Faculty of Engineering, Diponegoro University, Semarang, Central Java, Indonesia

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ABSTRACT
The performance and reliability of the SPP module plays an important role in increasing the lifetime of the SPP module, together with the investment period, as an indicator that directly reduces the electricity cost or Levelized Cost of Energy (LCOE) of each SPP installation. In this study the aim was to analyze the effect, relationship and differences in changes in surface dirtiness of the module on the performance of the 50 kWp SPP UPDL Makassar both through frequency intervention and maintenance methods. The results showed that the most optimal maintenance method was the rubbing method with optimal time and cost maintenance in a period of 2 weeks, besides that if maintenance was carried out before entering the rainy season, the module cleanliness pattern was in accordance with previous conditions, even though the amount of output produced was smaller due to reduced radiation values. This study also shows that one of the significant factors on the output of SPP is the impact of shadows on the surface of the module.
Keywords: Solar PV, Maintenance, Method, Optimal and Shading

I. INTRODUCTION

The performance and reliability of the Solar PV Power Plant (SPP) module plays an important role in increasing the lifetime of the SPP module, together with the investment period, as an indicator that directly reduces the electricity cost or Levelized Cost of Energy (LCOE) of each SPP installation. However, a complete understanding of PV modules on the impact of degradation on PV mini-grid performance is far from complete, and extensive efforts must be made to achieve and guarantee at least 25 years of PV module operating life with high reliability and performance in any climatic conditions. Where, climatic conditions have an important role in determining the level of degradation and the main cause of failure of the SPP module. As a consequence, feedback of PV mini-grid installations under different climates and regions is necessary in terms of degradation, failure to enrich the database of performance and reliability of PV mini-grid systems globally [1].

The effect of dust also plays an important role in the performance of solar modules [2]. Dust accumulation in SPP panels depends on two interrelated parameters such as the local environment and dust properties. The local environment refers to climatic conditions, geographical, location, type of vegetation and human activities at the site while the nature of the dust represents the size, weight, components and morphology of the dust particles. The surface of the SPP module is also a major contributor to dust accumulation on it. In addition, the tilt of the SPP panels is also an important parameter in dust accumulation because the smaller the angle of inclination, the higher the accumulated dust. In addition, high wind speeds can clear dust although slow winds can allow dust accumulation [3].

Soiling can cause more than 1% power loss per day and is a site-specific phenomenon, greatly affected by local climatic conditions. The predominant type of contamination can change significantly depending on location, mineral dust deposits, bird droppings, bacterial biofilms, algae, lichens, lichens, or molds, plant debris or pollen, engine exhaust or industrial emissions, and agricultural emissions such as bait dust. . For PV modules, fouling on the windshield mainly results in optical loss due to light absorption or backward scattering, depending on the area shaded by the impurity particles and also on the dust composition and particle size distribution.

In cases where cleaning is not carried out, layers of cemented dust, mildew and mold are practically impossible to remove, whereas harsh cleaning can lead to scratches or abrasion of the anti-reflective coating (ARC) or corrosion of the glass. In addition, mechanical loads during cleaning or thermal shock when hot elements are cleaned with cold water can lead to damage to the solar cells and glass or expansion of micro-cracks. Furthermore, the potential for induced degradation (PID) in PV mini-grid can be increased by fouling, and partial shading due to non-uniform fouling can lead to the formation of hot spots. Today, cleaning is the most sophisticated way to deal with dirtiness. The economics of cleaning up also determines the economic feasibility of other mitigation technologies. Therefore, the techno-economic feasibility of the potential technology is investigated on the basis of evaluating its efficiency in dirt loss reduction and potential costs [4].

Variations in climatic conditions from one location to another around the world have corresponding effects on the performance of the PV mini-grid modules in different regions [5]. Parameters that can affect the performance of the SPP module include solar radiation, wind speed, rainfall, temperature, humidity, and the possibility of the presence of dust. The following sub-sections summarize the effect of each of these conditions on the performance of the PV mini-grid module.

2.1. Effect of wind speed

Wind speed can have both positive and negative effects on the performance of the PV mini-grid module. The impact of wind speed on the performance of the PV mini-grid module is primarily a function of wind speed and direction, surface structure of the PV mini-grid module, and dust deposition. In the outdoor environment, wind speed, ambient temperature, surface structure and solar radiation affect the module temperature.

2.1.1. Impact of dust deposition

Wind blows dust particles off the surface of the PV module, which can reduce dust deposition. In Egypt, it was observed that a decrease in the dust deposition rate occurred in the module at a certain angle of inclination because the wind blew after 2 weeks of exposure to weather conditions [6]. The performance of the SPP module was reduced due to the amount of dust accumulated on the surface covering the SPP panel thus blocking solar radiation from occurring at various geographic conditions and the type of module technology [7], [8].

II. MATERIALS AND METHODS

a. Research Location and Schedule

The research will be conducted at SPP 50 kWp UPDL Makassar, Gowa, South Sulawesi. The research was carried out in the period September 2022.

Table 1

SPP System Specifications

No	Item	Value
1	System Type	On Grid System
2	System Capacity	50 kWp
3	Number of Arrays	5
4	Number of Strings	10
5	Number of solar modules	160
6	Number of modules/strings	16
7	Number of strings/arrays	2

This is an experimental research, according to Solso & MacLin (2002), experimental research is a study in which at least one manipulated variable is found to study cause-and-effect relationships. Therefore, experimental research is closely related to testing a hypothesis in order to look for influences, relationships, or differences in changes in the groups subject to treatment. In this study the aim was to analyze the effect, relationship and differences in changes in surface dirtiness of the module on the performance of the 50 kWp SPP UPDL Makassar both through frequency intervention and maintenance methods.

b. Types and Sources of Data

This study uses primary and secondary data. Primary data is directly obtained from the results of measurements and observations at the research location, while secondary data comes from a literature review in the form of data that supports analysis related to research. The primary data in this study were obtained from observations and measurements in the form of:

1. Data from current, voltage, power and energy measurements of SPP UPDL Makassar obtained on the website sunnyportal.com
2. Data from radiation sensor measurements and temperature and wind speed installed at the location of the SPP system

While the secondary data used in this study is in the form of literature data such as SNI standards and previous research data in the form of journals, articles, websites, climate data and various other sources. Secondary data is used to facilitate research, guide research, and strengthen research results.

C. Data Collection Techniques

Primary and secondary data collection techniques to be used in research are carried out by:

a. Observation and Adjustment of research objects

Observation and adjustment of the research object is carried out by:

1. Observing the environmental conditions at the study site such as the potential for shadows, the condition of the surface of the array, the tightness of the nuts/bolts and the slope of the array.
2. Mark each scenario on each SPP string
3. Clean the entire surface of the solar module

b. Data measurement

Perform module cleaning

Module cleaning was carried out on the entire SPP array during the observation period, namely September 7 to September 27 2022, then periodic cleaning was carried out with a surface cleaning time span of every 1 week, 2 week,s and once every 4 weeks. Based on the following scenario (see figure 1):

1) Scenario 1 is carried out by cleaning with the rubbing method using water and a cloth/cleaning tool
2) Scenario 2 is carried out by cleaning with the soap-rubbing method using cleaning fluid, water and cloth/cleaning tools
3) Scenario 3 namely cleaning by spraying water on the surface of the module

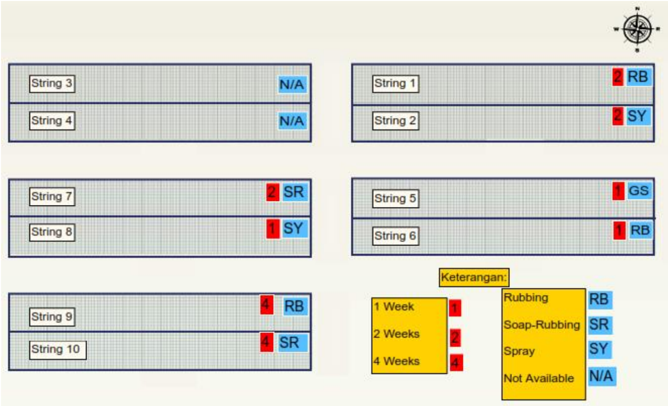

Figure 1: Description of Research Scenario

III.RESULTS AND DISCUSSION

3.1 Measurement Results

Based on measurements that are carried out periodically in the period from 07 September 2022 to 27 September 2022, the Average Radiation and Temperature data are obtained as follows :

Table 2

Results of Radiation and Temperature Measurements

Parameter	Date													
	07-Sep	08-Sep	11-Sep	12-Sep	13-Sep	14-Sep	15-Sep	16-Sep	20-Sep	21-Sep	22-Sep	23-Sep	26-Sep	27-Sep
Radiation	399	417	617	638	542	456	348	556	417	475	360	532	314	527
Temperature	47.86	46.52	54.33	54.42	51.94	50.29	47.11	53.78	45.14	49.42	44.93	51.68	43.79	52.54

Based on the data presented in table 2, it can be seen that there are variations in radiation and temperature values at any time which indicate the intermittent characteristics of the SPP system. Meanwhile, Figure 2 shows that there is a linear correlation between the radiation values and temperature, which means that the changes between the two are consistent, if the radiation decreases, so does the temperature and vice versa. This can be observed based on the characteristics of the two identical parameters.

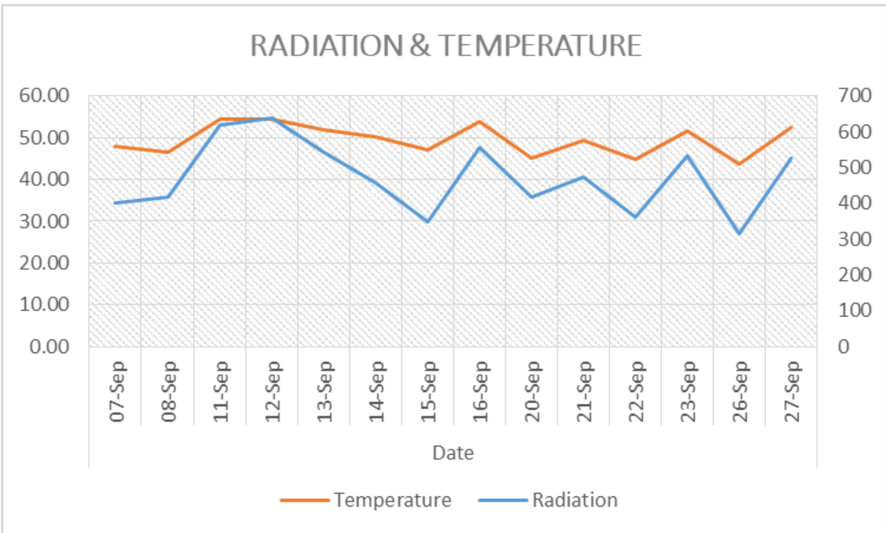

Figure 2: Radiation and Temperature Style

The important parameters observed in this study are the current and output voltage values of each maintenance method based on the maintenance period.

The following is the average current based on the maintenance period:

1. Maintenance per week

a. Average current on maintenance per week

Table 3

Average Output Current Based on Weekly Maintenance Period

Method	Date													
	07-Sep	08-Sep	11-Sep	12-Sep	13-Sep	14-Sep	15-Sep	16-Sep	20-Sep	21-Sep	22-Sep	23-Sep	26-Sep	27-Sep
Soap-Rubbing	3.31	3.37	5.17	5.31	4.45	3.83	2.95	4.77	3.40	3.89	2.96	4.42	2.64	4.52
Rubbing	3.37	3.43	5.28	5.42	4.54	3.84	2.94	4.78	3.39	3.89	2.96	4.45	2.64	4.51
Spray	3.17	3.38	5.10	5.25	4.35	3.77	2.80	4.57	3.26	3.82	2.89	4.29	2.56	4.34

Based on table 3, it shows that there are variations in the output current for each maintenance method which is then presented in Figure 3 and shows that all methods have identical output styles, even though the maintenance with the rubbing method has a higher output than the other methods.

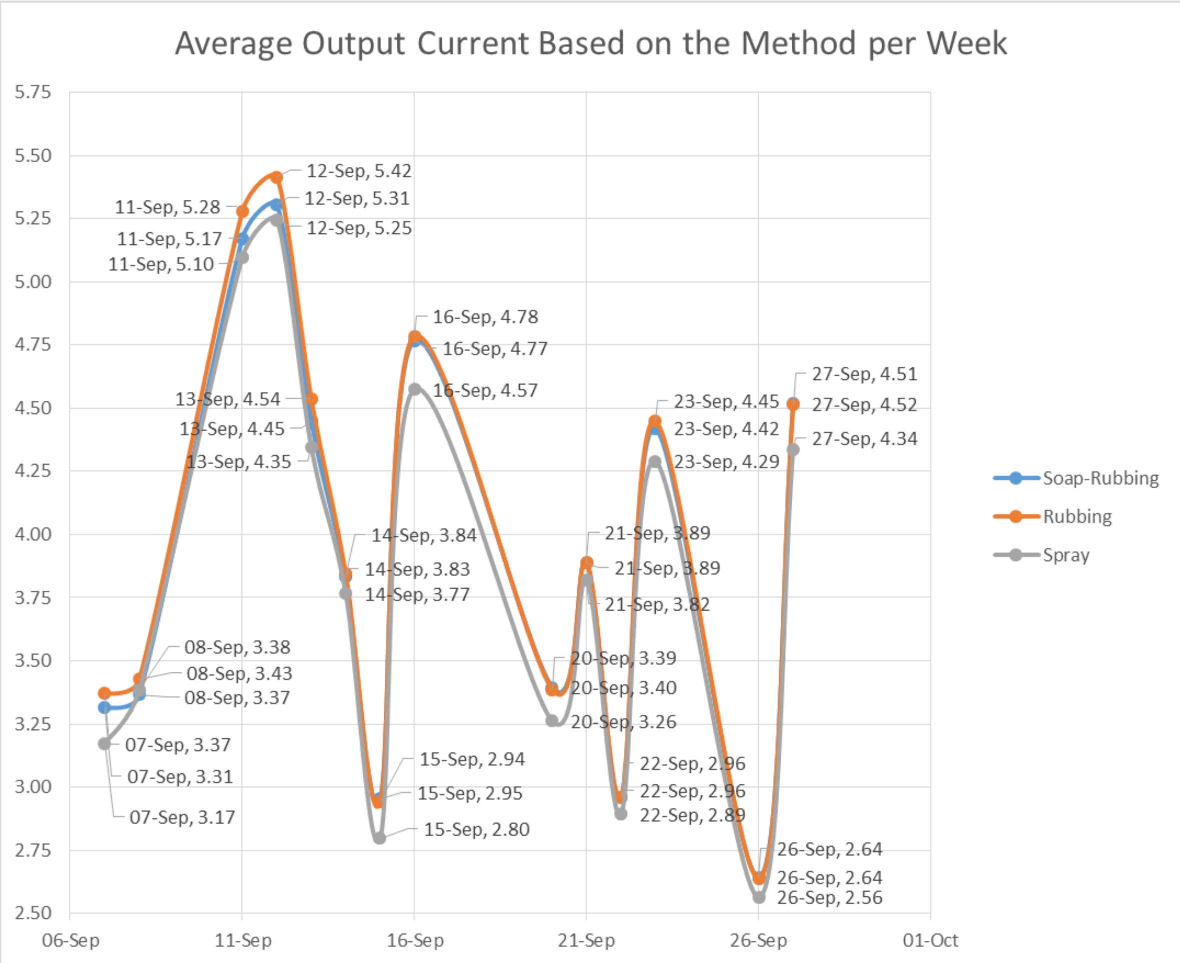

Figure 3: Average Output Current by Method per Week

In addition, Figure 4 shows a graph of the average current based on the maintenance method, showing that the rubbing maintenance method has an average current of 3.96 A or about 0.78% higher than the soap rubbing method with an average output of 3.93 A and the spray maintenance method with the average value of the output current is 3.83 A or a difference of 3.28% lower when compared to the rubbing maintenance method. This shows that the spray method has a significant difference in output compared to the other 2 methods.

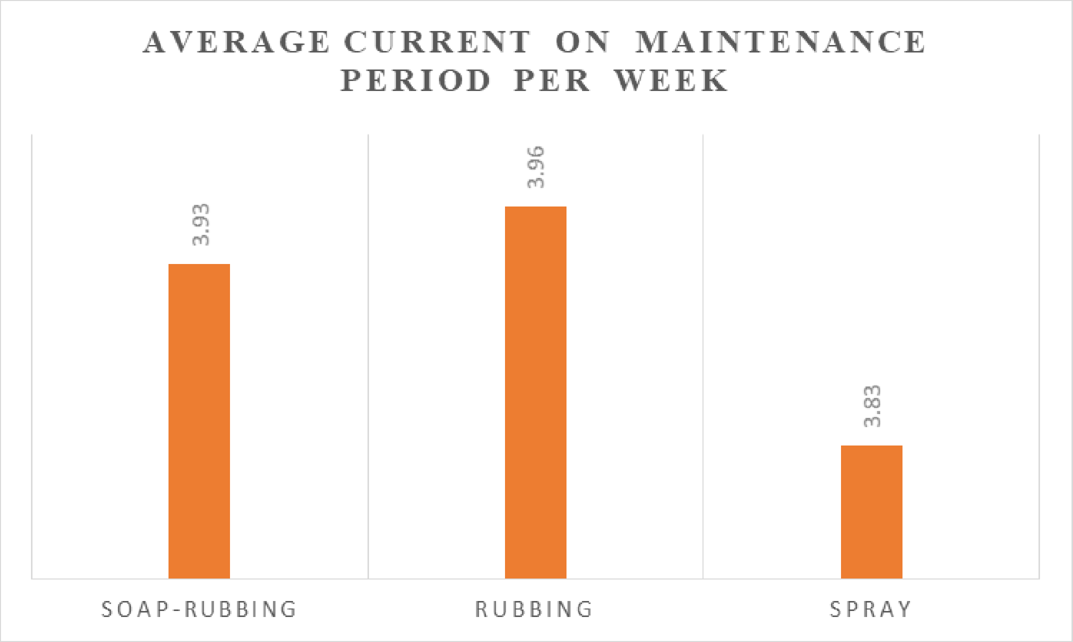

Figure 4: Average Current in the Maintenance Period per Week

b. Average voltage on maintenance per week

Table 4

Average Output Voltage Based on Weekly Maintenance Period

Method	Date													
	07-Sep	08-Sep	11-Sep	12-Sep	13-Sep	14-Sep	15-Sep	16-Sep	20-Sep	21-Sep	22-Sep	23-Sep	26-Sep	27-Sep
Rubbing	525	509	508	505	511	514	524	512	521	514	523	513	516	510
Soap-Rubbing	523	510	505	503	508	516	526	512	520	516	524	514	518	509
Spray	525	511	496	493	500	513	527	509	517	514	523	505	519	509
Temperature	47.86	46.52	54.33	54.42	51.94	50.29	47.11	53.78	45.14	49.42	44.93	51.68	43.79	52.54

Based on table 4, it shows that there are variations in the output voltage for each maintenance method which is then presented in Figure 5 and shows that all methods have identical output styles, even though the maintenance with the spray method has a lower output voltage than the other methods.

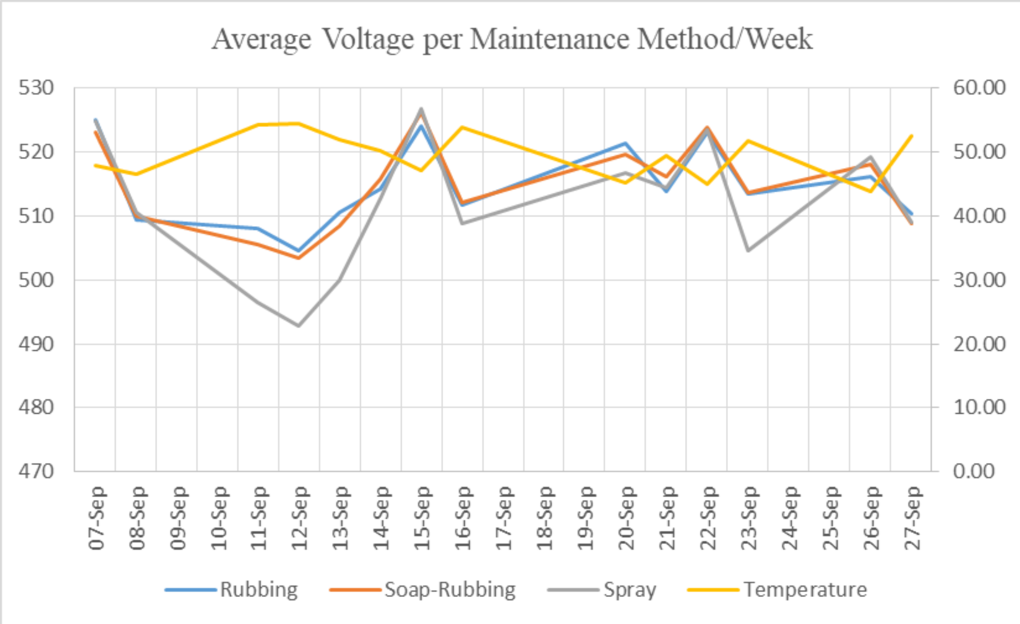

Figure 5: Average Voltage per Maintenance Method/Week

The comparison between voltage and temperature in each method can be observed in Figure 5 where the graph shows that the temperature is inversely proportional to the voltage value, where in the graph it can be seen that the spray method has a very significant difference compared to other methods, this is in line with the amount of current which is in the weekly period the current value in the spray method has the smallest output value as previously discussed.

2. Maintenance every 2 weeks

a. Average current on maintenance per week

Table 5 Average Output Current Based on 2 Weeks Maintenance Period

METHOD	DATE													
	07-Sep	08-Sep	11-Sep	12-Sep	13-Sep	14-Sep	15-Sep	16-Sep	20-Sep	21-Sep	22-Sep	23-Sep	26-Sep	27-Sep
Rubbing	3.37	3.43	5.30	5.45	4.55	3.81	2.90	4.75	3.37	3.89	2.94	4.45	2.62	4.53
Soap-Rubbing	3.17	3.41	5.15	5.31	4.36	3.78	2.78	4.59	3.27	3.87	2.92	4.35	2.58	4.39
Spray	3.33	3.39	5.21	5.35	4.48	3.77	2.89	4.69	3.34	3.83	2.91	4.37	2.59	4.51

Based on table 5, it shows that there are variations in the output current for each maintenance method which is then presented in Figure 6 and shows that all methods have identical output styles, even though the maintenance with the brush maintenance method has a higher output current than the other methods.

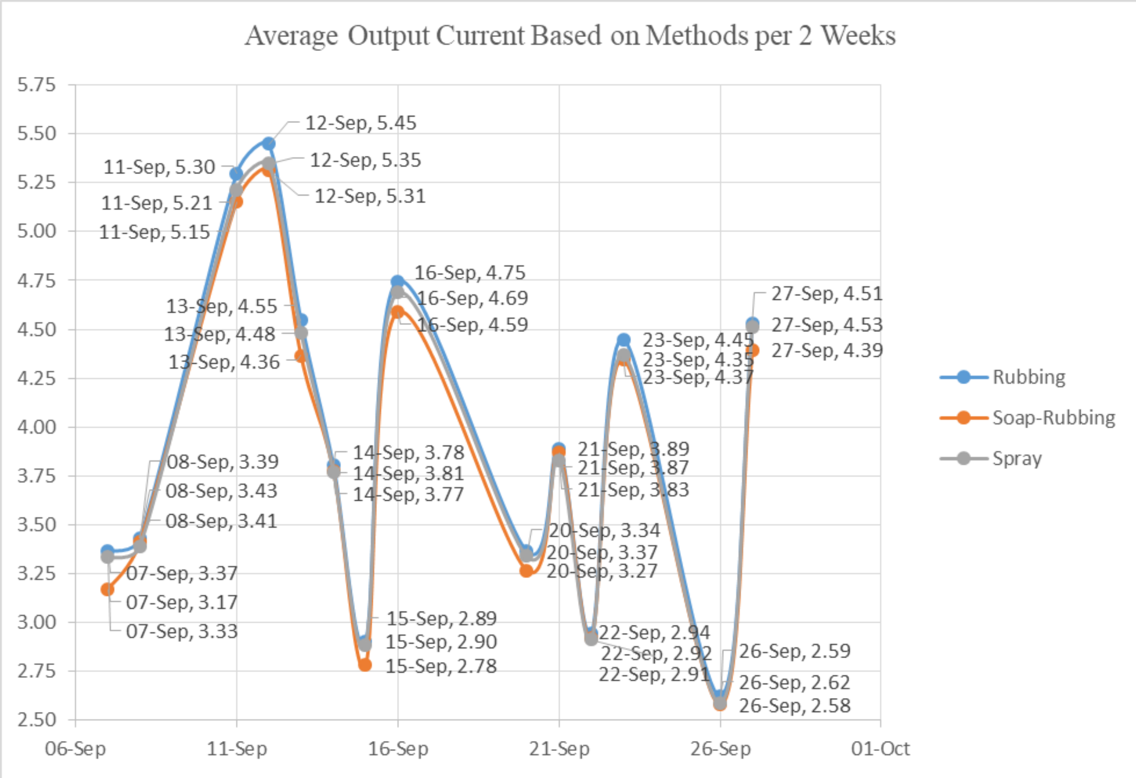

Figure 6: Average Output Current Based on Methods per 2 Weeks

In the 2-week maintenance, it can be seen that the rubbing maintenance method has the highest output with an average current of 3.95 A or 1.27% greater than the spray maintenance method which is in second place with an average output of 3.9 A, and when compared with the maintenance soap-rubbing method has a difference of 2.5% greater than the average output in the soap-rubbing method of 3.85 A.

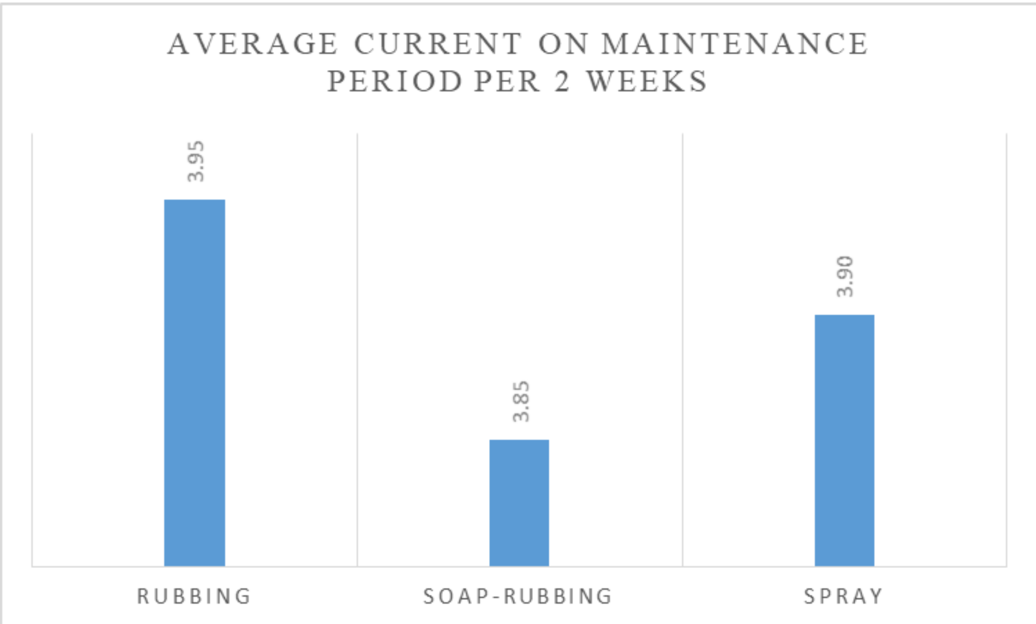

Figure 7: Average Current in the Maintenance Period per 2 Weeks

In Figure 7 it can be seen that the soap-rubbing maintenance method has the smallest average output compared to other maintenance methods which is different from weekly maintenance, this is caused by the impact of the tree's shadow on the soap-rubbing method which is in array 4 as shown in figure 8.

Figure 8: Photo of Tree Shadows on Array Surface 4

Figure 9 shows a comparison of the output styles of array 3 and array 4, where in the afternoon the output of array 4 has decreased and is not linear in relation to the amount of radiation caused by the shadows that occur in the afternoon from 14.30 to 16.10 WITA.

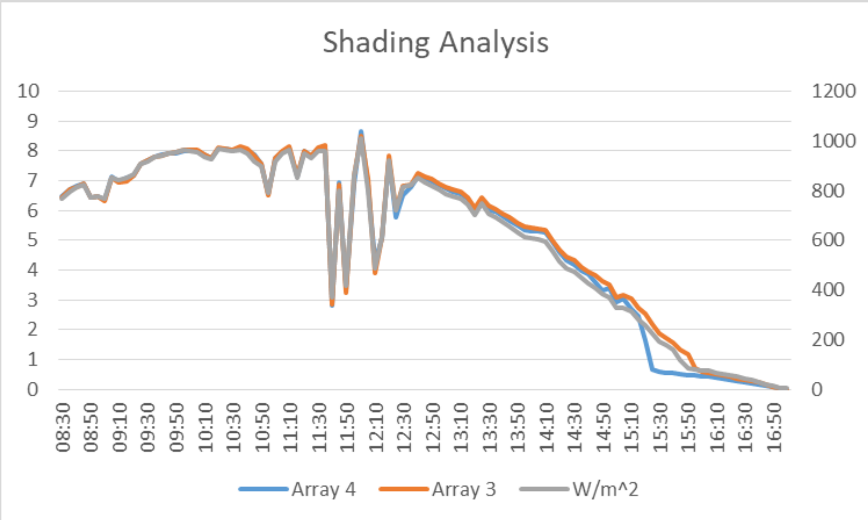

Figure 9: Graph of Comparison of Output Styles in Arrays 3 and 4

b. Average voltage on maintenance per 2 weeks

Table 6

Average Output Voltage Based on Weekly Maintenance Period

Method	Date													
	07-Sep	08-Sep	11-Sep	12-Sep	13-Sep	14-Sep	15-Sep	16-Sep	20-Sep	21-Sep	22-Sep	23-Sep	26-Sep	27-Sep
Soap-Rubbing	527	513	511	508	515	519	528	517	521	517	526	518	521	512
Rubbing	529	513	491	491	501	517	530	511	517	516	524	505	520	510
Spray	528	512	509	509	511	517	527	515	520	515	526	516	521	507
Temperature	47.86	46.52	54.33	54.42	51.94	50.29	47.11	53.78	45.14	49.42	44.93	51.68	43.79	52.54

Based on table 6, it shows that there are variations in the output voltage for each maintenance method which is then presented in Figure 10 and shows that all methods have identical output styles, even though the maintenance with the soap-rubbing method has a lower output voltage than the other methods.

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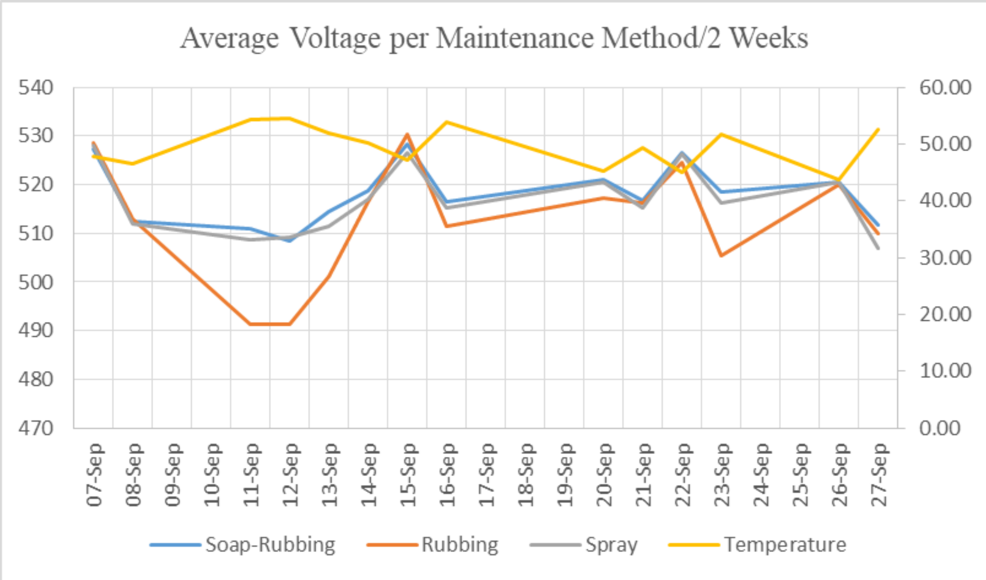

Figure 10: Average Voltage per Maintenance Method/2 Weeks

3. Maintenance every 4 weeks

a. Average current on maintenance per week

Table 7

Average Output Current Based on 4 Weeks Maintenance Period

METHOD	DATE													
	07-Sep	08-Sep	11-Sep	12-Sep	13-Sep	14-Sep	15-Sep	16-Sep	20-Sep	21-Sep	22-Sep	23-Sep	26-Sep	27-Sep
Soap - Rubbing	3.27	3.37	5.15	5.30	4.43	3.75	2.83	4.62	3.29	3.80	2.88	4.30	2.55	4.39
Rubbing	3.21	3.43	5.23	5.39	4.49	3.82	2.85	4.70	3.32	3.88	2.93	4.39	2.59	4.45

Based on table 7, it shows that there are variations in the output current for each maintenance method which is then presented in Figure 11 and shows that all methods have identical output styles, even though the maintenance with the rubbing method has a higher output than the soap-rubbing maintenance method.

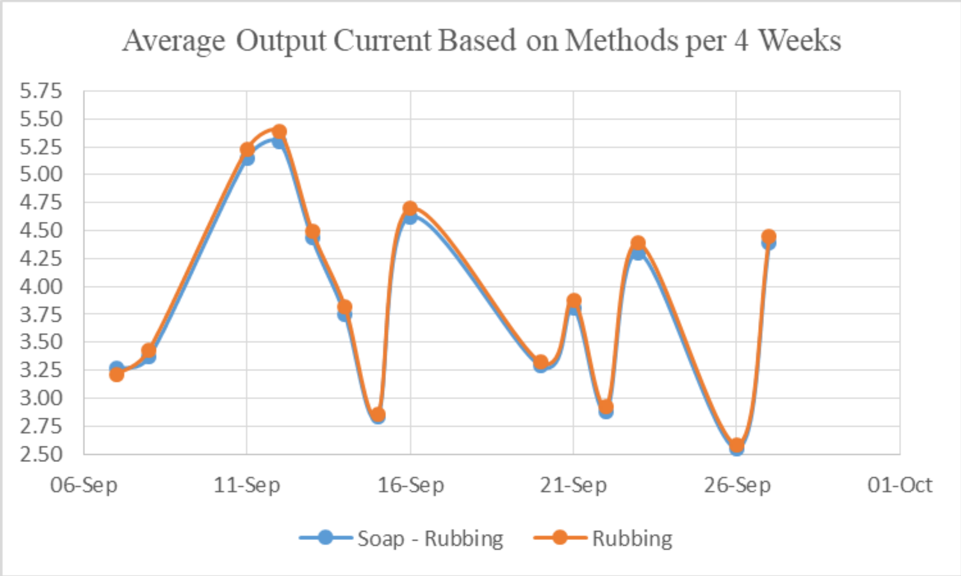

Figure 11: Average Output Current by Method per 4 Weeks

For 4-week maintenance, Figure 12 shows a comparison between the rubbing method and soap-rubbing method, where the average output of the rubbing method is 3.91 A or 1.53% higher than the soap-rubbing method with an average value of 3.85 A.

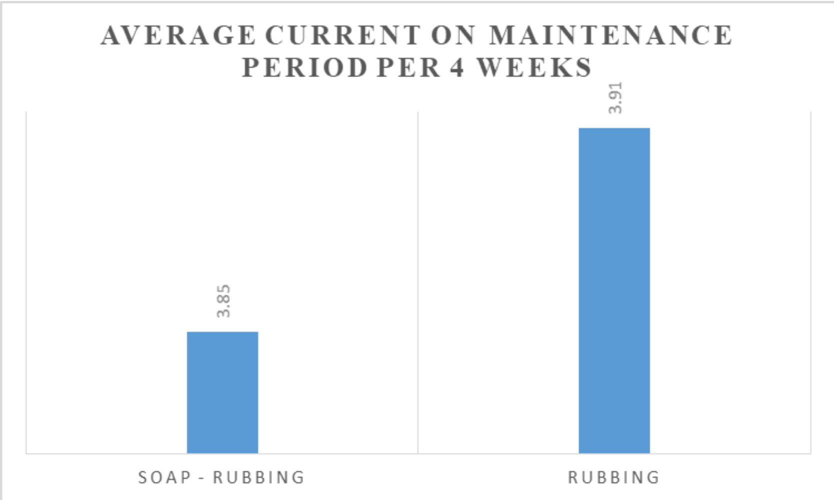

Figure 12: Average Current in the Maintenance Period per 4 Weeks

b. Average voltage on maintenance per 4 weeks

Table 8

Average Output Voltage Based on 4 Weeks Maintenance Period

Method	Date													
	07-Sep	08-Sep	11-Sep	12-Sep	13-Sep	14-Sep	15-Sep	16-Sep	20-Sep	21-Sep	22-Sep	23-Sep	26-Sep	27-Sep
Soap-Rubbing	519	512	502	496	501	513	524	506	517	516	523	516	520	499
Rubbing	528	511	500	500	501	513	524	509	521	513	524	514	519	505
Temperature	47.86	46.52	54.33	54.42	51.94	50.29	47.11	53.78	45.14	49.42	44.93	51.68	43.79	52.54

Based on table 8, it shows that there are variations in the output voltage for each maintenance method which is then presented in Figure 13 and shows that all methods have identical output styles, even though the maintenance with the rubbing maintenance method has a higher output voltage than the soap-rubbing maintenance method.

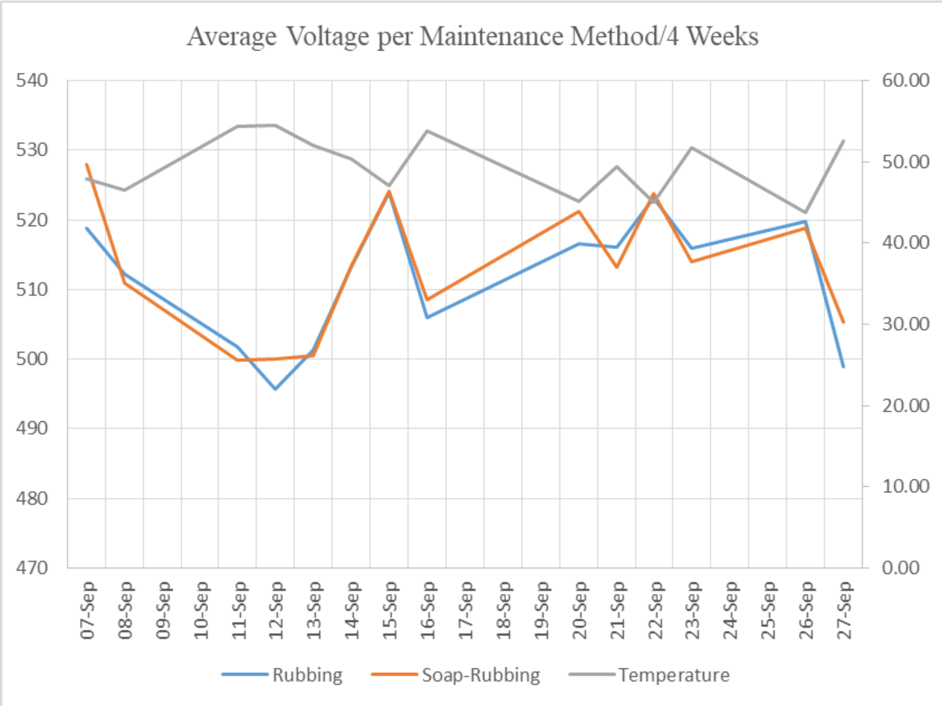

Figure 13 Average Voltage per Maintenance Method/4 Weeks

4. Maintenance During Rainy Season Period

a. Maintenance per week

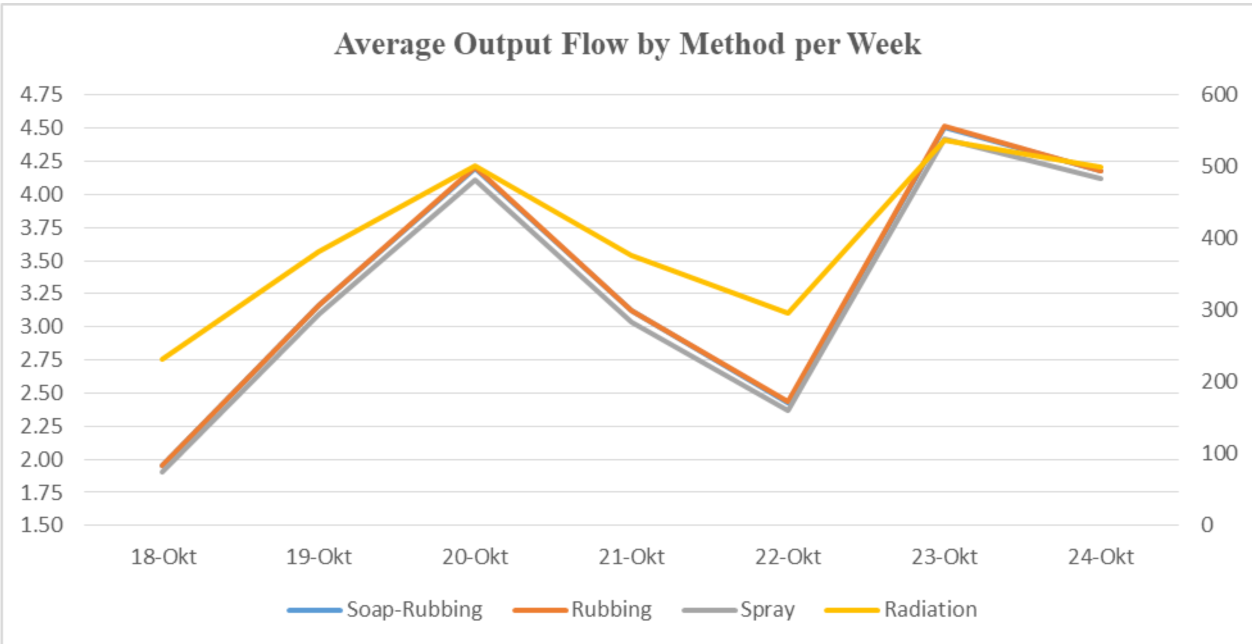

Figure 14: Average Output Current by Method per Week

The variation of the output current for each maintenance method which is then presented in Figure 14 shows that all methods have identical output patterns, even though the maintenance with the soap-rubbing method has a higher output than the other methods.

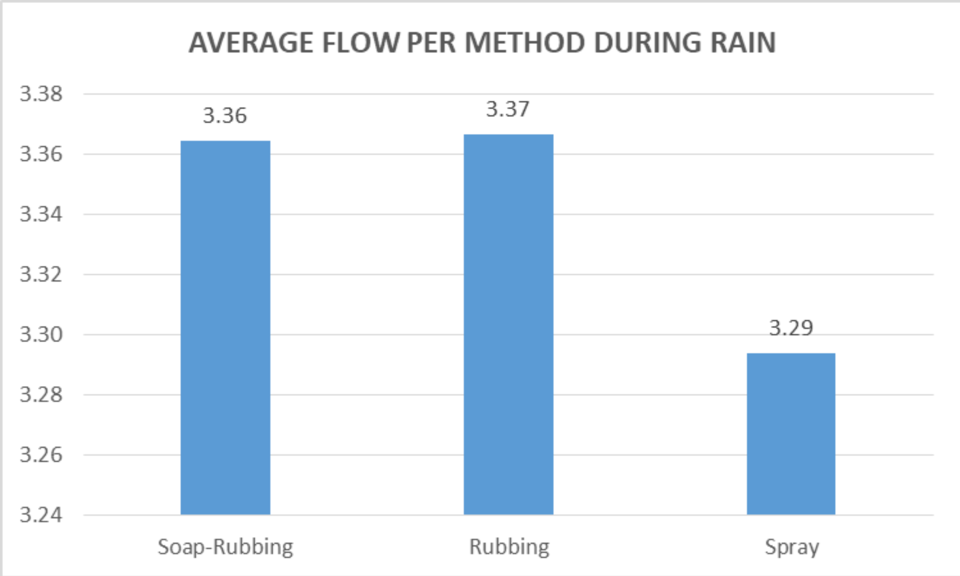

Figure 15: Average Current per Method During Rain

In addition, Figure 15 shows a graph of the average current based on the maintenance method, showing that the rubbing maintenance method has an average current of 3.37 A or about 0.3% higher than the soap-rubbing method with an average output of 3.36 A and the spray maintenance method with the average value of the output current is 3.29 A or a difference of 2.37% lower when compared to the rubbing maintenance method. This shows that the spray method has a significant difference in output compared to the other 2 methods.

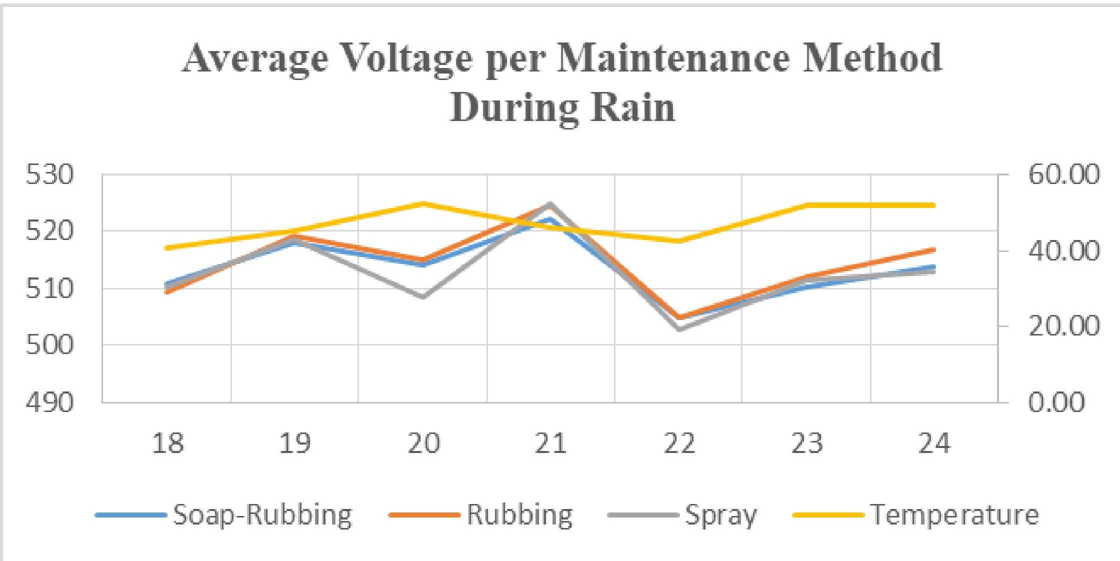

Figure 16: Average Voltage per Maintenance Method During Rain

Maintenance Method When It Rains The comparison between voltage and temperature in each method can be observed in Figure 16 where the graph shows that the temperature is inversely proportional to the voltage value, where in the graph it can be seen that the spray method has a significant difference compared to other methods, this is in line with the amount of current in which the the weekly period of the current value in the spray method has the smallest output value as previously discussed.

b. Maintenance every 2 weeks

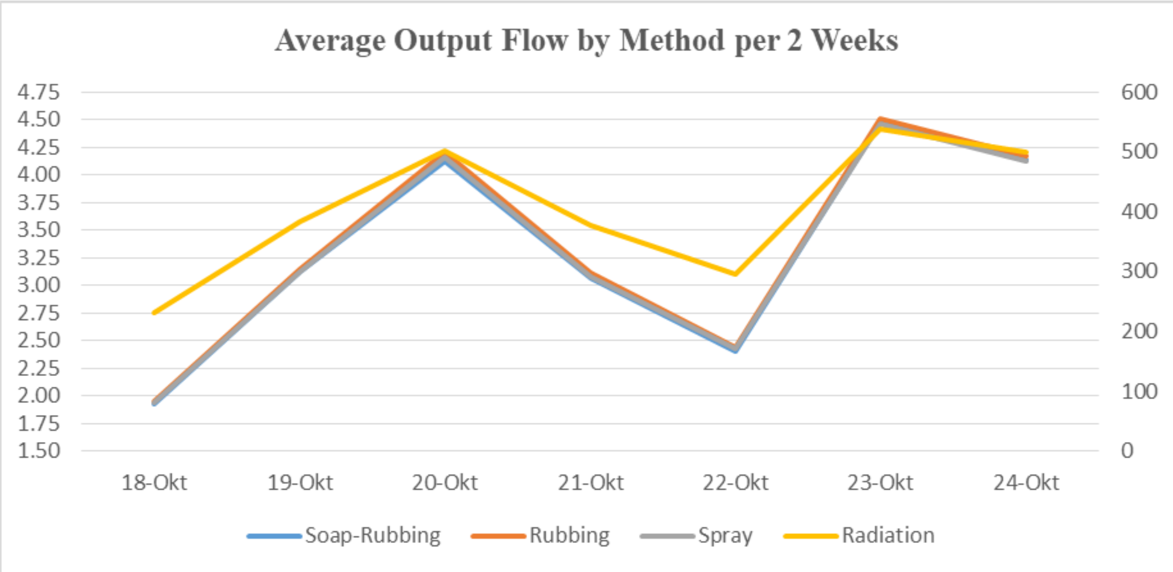

Figure 17: Average Output Current by Method per 2 Weeks

The variation of the output current for each maintenance method which is then presented in Figure 17 shows that all methods have identical output styles, even though the maintenance with the rub method has a higher output than the other methods.

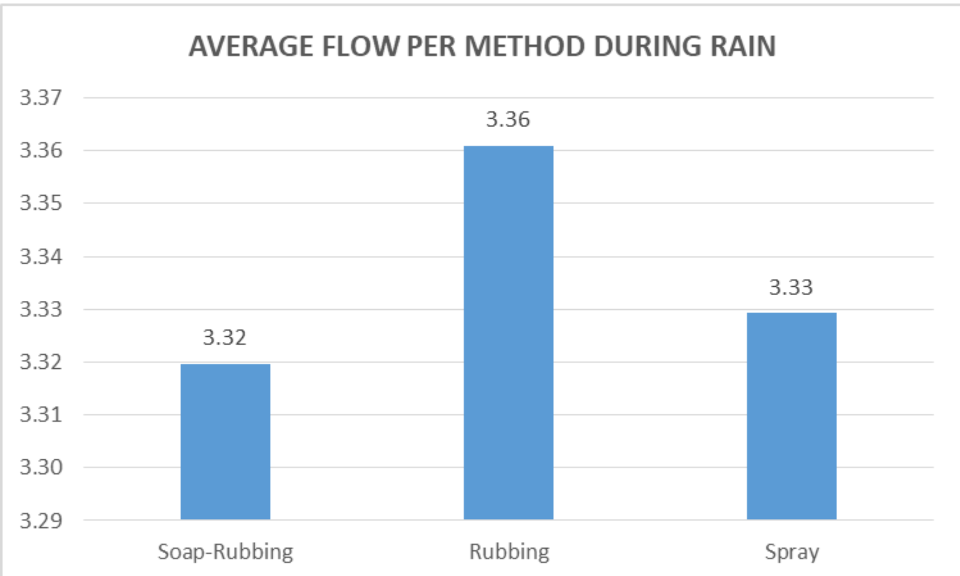

Figure 18: Average Current per Method During Rain

In addition, Figure 18 shows a graph of the average current based on the maintenance method, showing that the rubbing maintenance method has an average current of 3.36 A or about 0.89% higher than the spray method with an average output of 3.33 A and the soap-rubbing maintenance method with the average value of the output current is 3.32 A or a difference of 1.19% lower when compared to the rubbing maintenance method. This shows that the spray and rub methods have insignificant differences in output between the two.

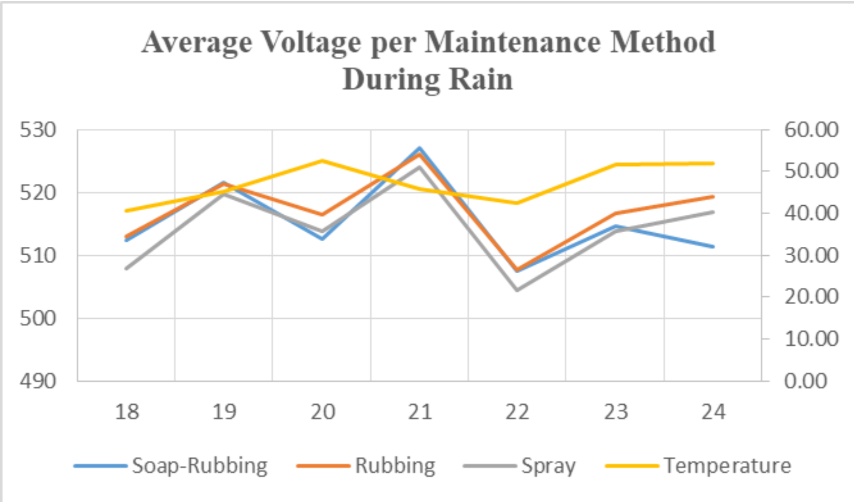

Figure 19: Average Voltage per Maintenance Method During Rain

Variations in the output voltage for each maintenance method, which is then presented in Figure 19, shows that all methods have an identical output signature, although the spray maintenance method has a lower output voltage than the other methods.

c. Maintenance per 4 weeks

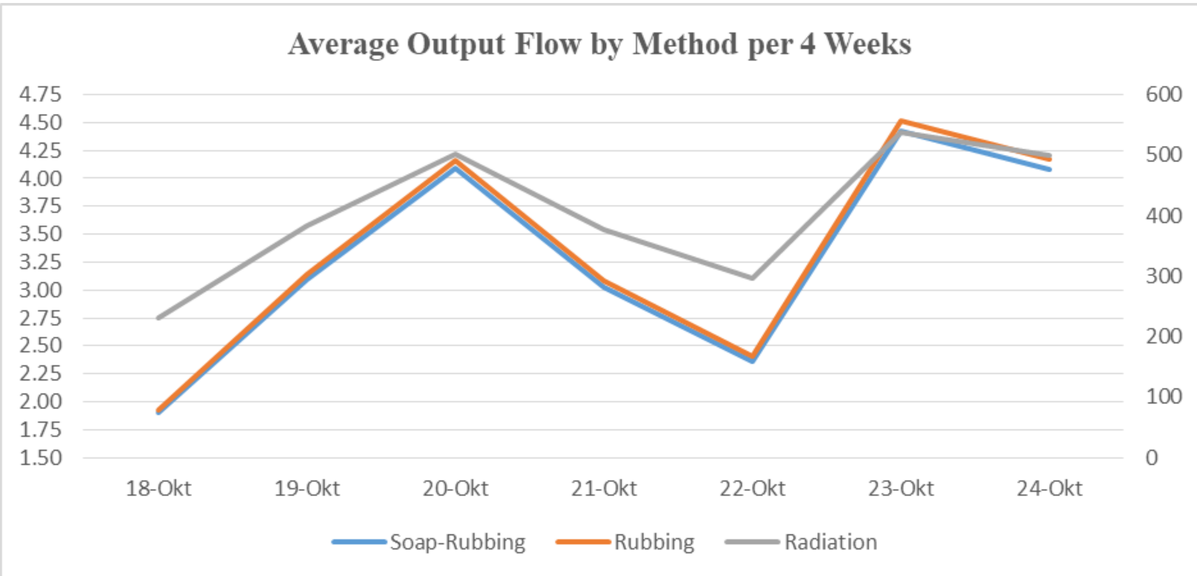

Figure 20: Average Output Current by Method per 4 Weeks

The variation of the output current for each maintenance method which is then presented in Figure 20 shows that all methods have identical output styles, even though the maintenance with the rubbing method has a higher output than the soap-rubbing method.

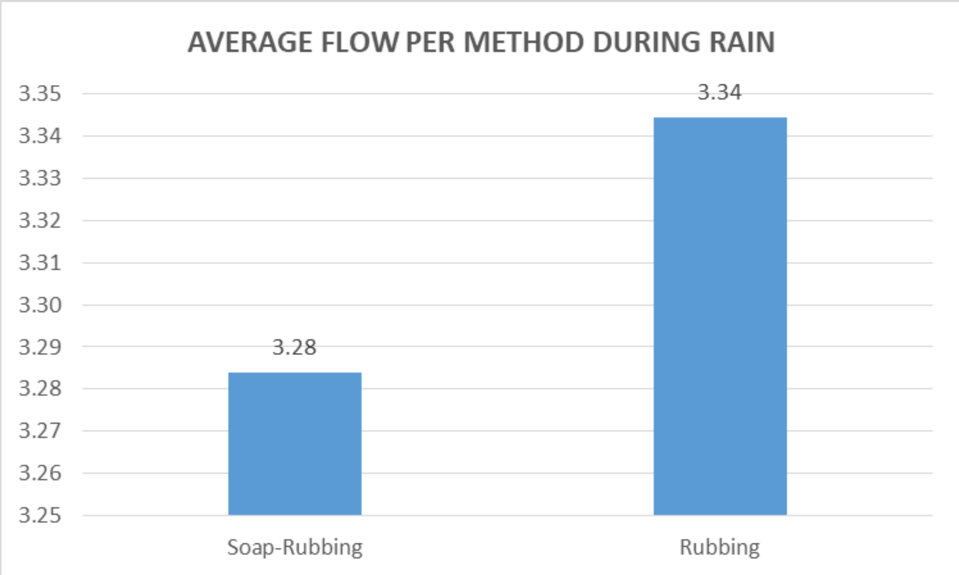

Figure 21: Average Current per Method During Rain

For 4-week maintenance, Figure 21 shows a comparison between the rubbing and soap-rubbing methods, where the average output of the rubbing method is 3.34 A or 1.8% higher than the soap-rubbing method with an average value of 3.28 A.

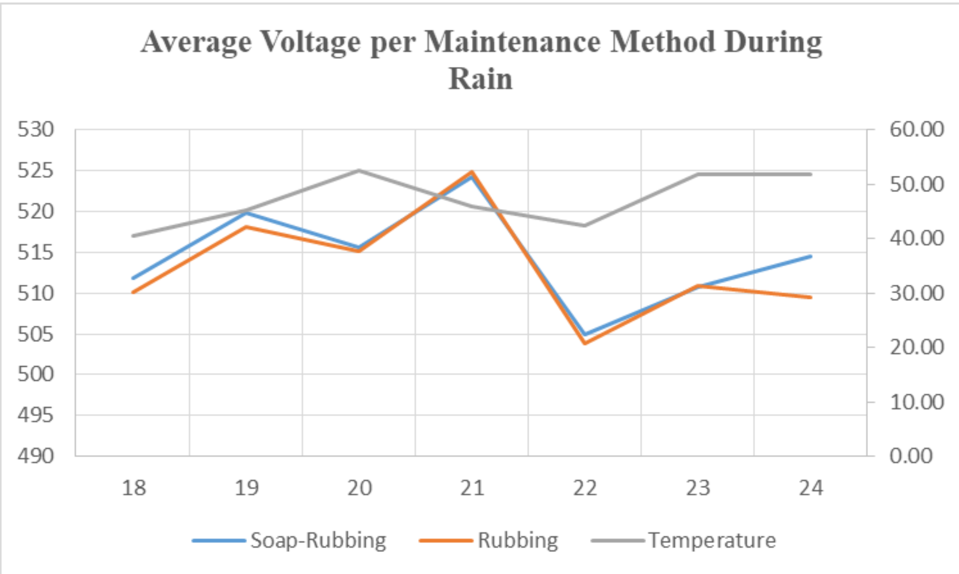

Figure 22: Average Voltage per Maintenance Method During Rain

Variations in the output voltage for each maintenance method, which is then presented in Figure 22, shows that all methods have identical output patterns, although the rubbing maintenance method has a lower output voltage than the soap-rubbing method.

3.2 Discussion

a. Before maintenance

Based on data analysis prior to maintenance, it can be seen that the output strings for each period are shown in Figure 23, where the weekly period is carried out on array 3 and array 4, the 2 week period is carried out on array 1 and array 4 and for the 4 week period it is carried out on arrays 5.

the output of each string on the same array can be observed as follows:

a. The output of array 1 was 3.89 A and 3.91 A respectively which were used as a comparison for the rubbing and soap-rubbing maintenance methods in the maintenance period of 2 weeks;

b. The output of array 3 is 4.07A and 4.08A respectively which are used as a comparison for the results of research using the rubbing and soap-rubbing methods on a period of per week;

c. The output of array 4 is 3.99 A and 4.04 A respectively which are used as a comparison for the spray method in the maintenance period per week and per 2 weeks;

d. The output of array 5 is 3.63A and 3.90A respectively which are used as a comparison for the rubbing and soap-rubbing maintenance methods at maintenance per 4 weeks.

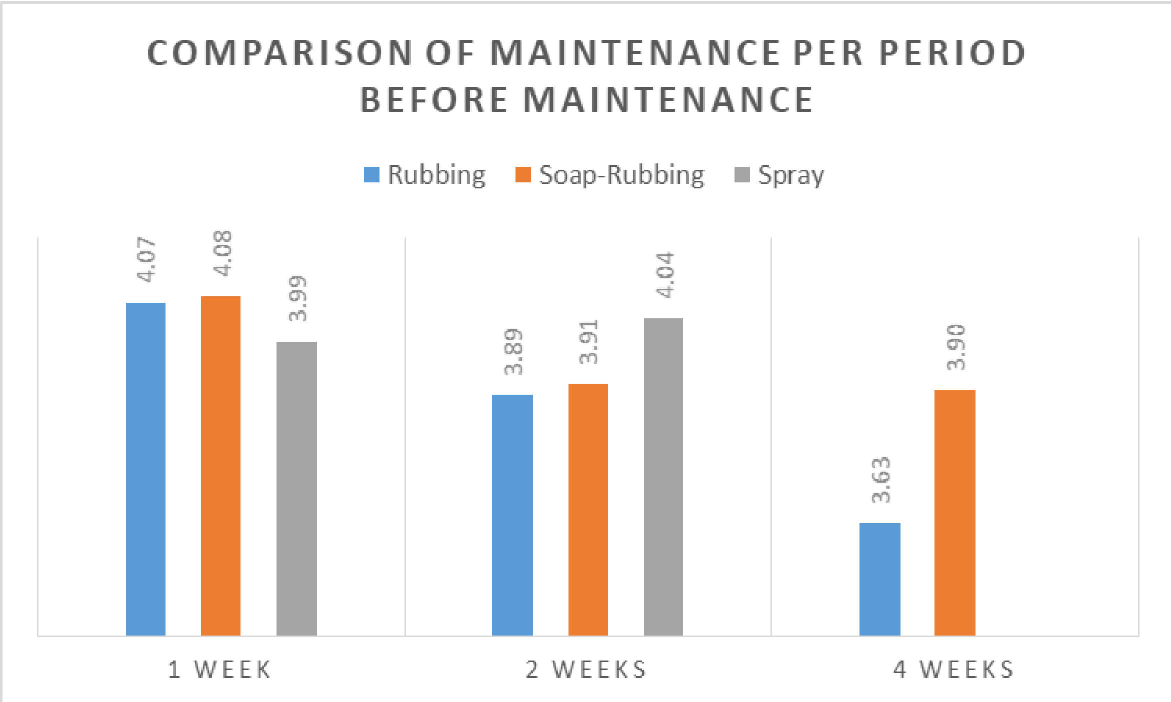

Figure 23: Comparison of Maintenance per Pre-Maintenance Period

b. After maintenance

Based on the measurement results previously stated, the average output of each method and maintenance period is shown in Figure 24. Based on the output style after maintenance, it can be observed that the maintenance method and period have an impact on the output of the SPP system with the following analysis:

a. in maintenance per week the scrub method has the highest output compared to other methods seen in different output styles including styles before maintenance;

b. in the maintenance per 2 weeks, it is also seen that the rubbing method has the greatest output compared to other methods, but one of the contributing factors is the occurrence of shadows on the surface of the module as discussed previously;
c. on maintenance per 4 weeks, it was also seen that maintenance with the rubbing method had a greater output compared to the rubbing method.

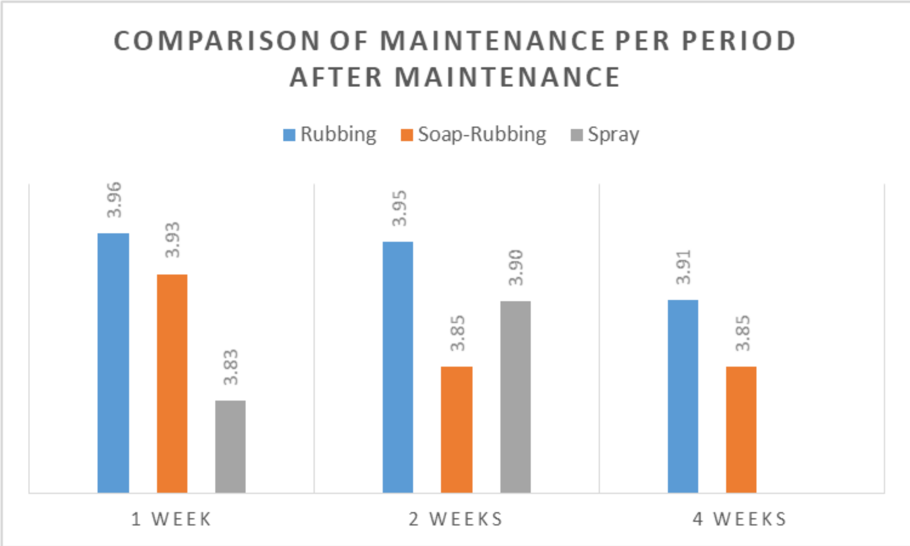

Figure 24: Comparison of Maintenance per Period After Maintenance

c. During the rainy season period

Meanwhile for maintenance during the rainy season, if maintenance is carried out before entering the rainy season, it can be seen that the output style of the SPP is identical to the routine maintenance style, even though the average output value has decreased due to a decrease in the radiation value as shown in Figure 25.

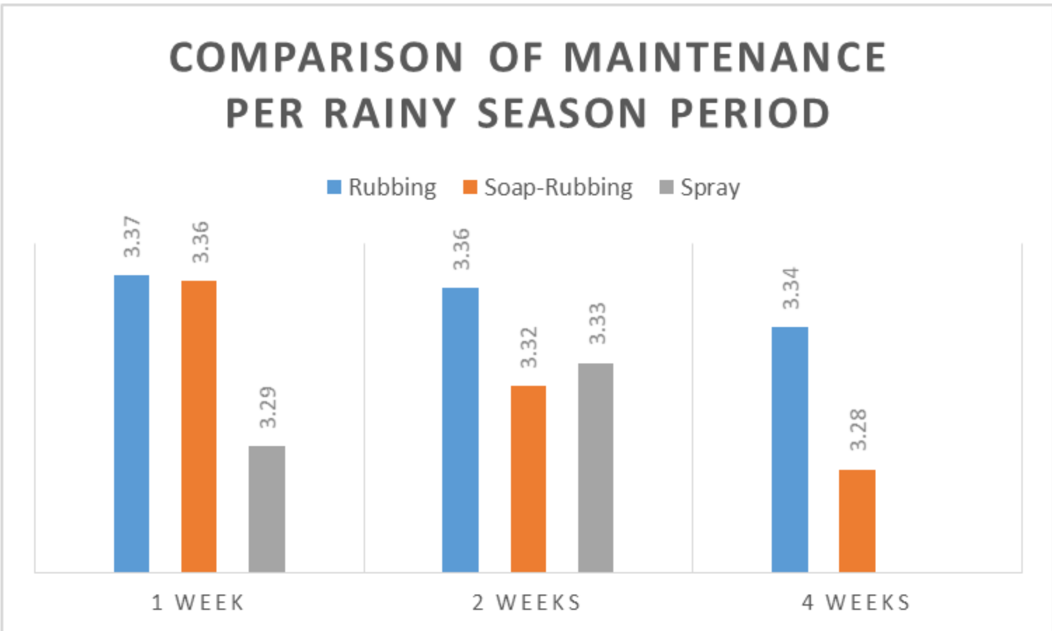

Figure 25: Comparison of Maintenance per Rain Period

d. Power Output Analysis

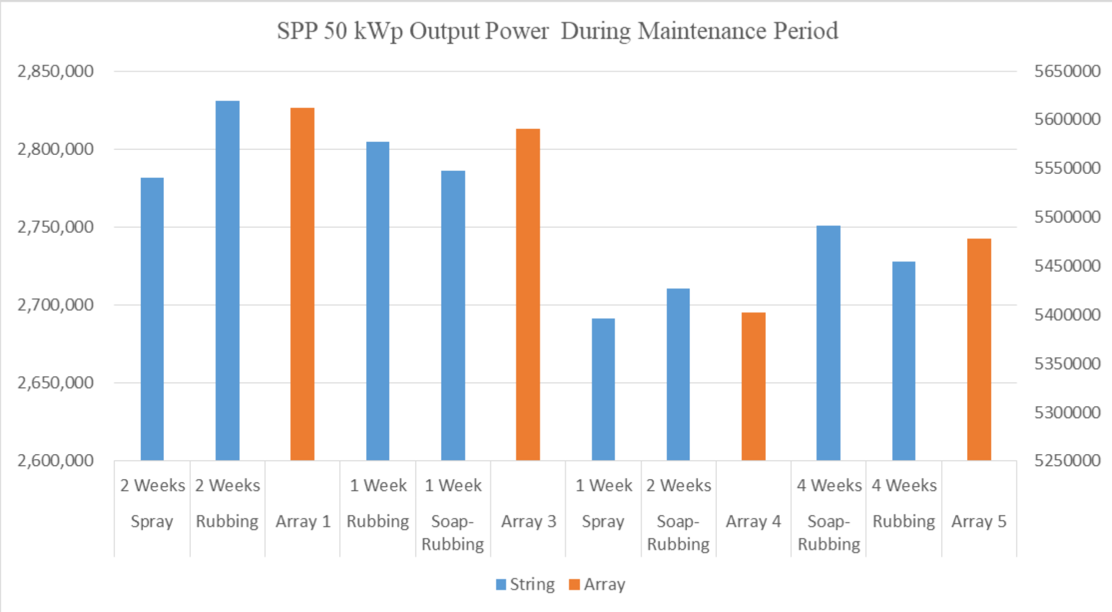

Figure 26: Power Output of 50 kWp SPP in the Maintenance Period

Figure 26 above shows that the largest power output during the observation period is located in Array 1. In Array 1, the output of the rubbing method is greater than that of the spray method. As for array 3, it can be seen that the rubbing method has the largest output compared to the soap-rubbing method. In Array 4 the output of the soap-rubbing method is greater than the spray method, but if we compare it with the spray method in Array 1, it looks like an anomaly when compared between the 2-week periods in the spray method which has a larger output compared to the soap-rubbing method in array 4 which is caused by the shadow effect as stated in the previous discussion.

e. Cost Analysis

Table 9

Details of SPP Maintenance Needs

Item	Parameter	Size	Unit			
Water Container	Diameter	46	cm			
	High	43	cm			
	volume	71,426	cm3			
		0.071	m3			
Water Needs	Method	Volume	IDR/m3	IDR/String		
	Rubbing	0.071	4,000	284		
	Soap-Rubbing	0.1065	4,000	426		
	Spray	0.0355	4,000	142		
Electricity Needs	Method	Pump Duration (Minute)	Pump Power (Watt)	kWh/String	IDR/kWh	IDR/String
	Rubbing	20	550	0.18	1,444.70	264.86
	Soap-Rubbing	20	550	0.18	1,444.70	264.86
	Spray	8	550	0.07	1,444.70	105.94
Labor	Module/String	IDR/Module	IDR/String			
	16	5,000	80,000			
Sabun	IDR/Sachet					
	1,000					

Table 9 shows the cost calculation parameters for SPP surface maintenance which consist of water, electricity and labor requirements. Labor costs are one of the biggest cost components in the SPP maintenance process which is assumed to be IDR 5,000 per module. In addition, the cost of water requirements is calculated based on the amount of water used per string against the selling price of water which is assumed to be IDR 4,000 per M3 so that the cost per string is obtained for each method, each rubbing method is IDR 284 per string, the soap-rubbing method is IDR 426 per string and spray method Rp. 142 per string for each cleaning.

Meanwhile, for electricity needs using a 550 watt pump with a maintenance duration of 16 minutes per method each at a cost of IDR 211.89 per string for the rubbing method, 20 minutes for the rubbing method with a cost of IDR 264.86 per string and 8 minutes with costs IDR 105.94 per string for the spray method.

Table 10

Details of SPP Maintenance Costs

Method	Period	Frequency /Month	Monthly Costs (IDR)					
			Water Costs	Electricity Costs	Labor Cost	Soap Costs	IDR/String	IDR/SPP
Rubbing	1 Week	4	1,136	1,059	320,000		322,195	3,221,954
	2 Weeks	2	568	530	160,000		161,098	1,610,977
	4 Weeks	1	284	265	80,000		80,549	805,489
Soap-Rubbing	1 Week	4	1,704	1,059	320,000	2,000	324,763	3,247,634
	2 Weeks	2	852	530	160,000	1,000	162,382	1,623,817
	4 Weeks	1	426	265	80,000	500	81,191	811,909
Spray	1 Week	4	568	424	320,000		320,992	3,209,918
	2 Weeks	2	284	212	160,000		160,496	1,604,959
	4 Weeks	1	142	106	80,000		80,248	802,479

Furthermore, based on the costs in table 9, calculations are made for the monthly costs of each method as shown in table 10 which shows that maintenance costs are affected by the frequency of maintenance of the surface of the module, the more frequently it is maintained, the greater the costs required.

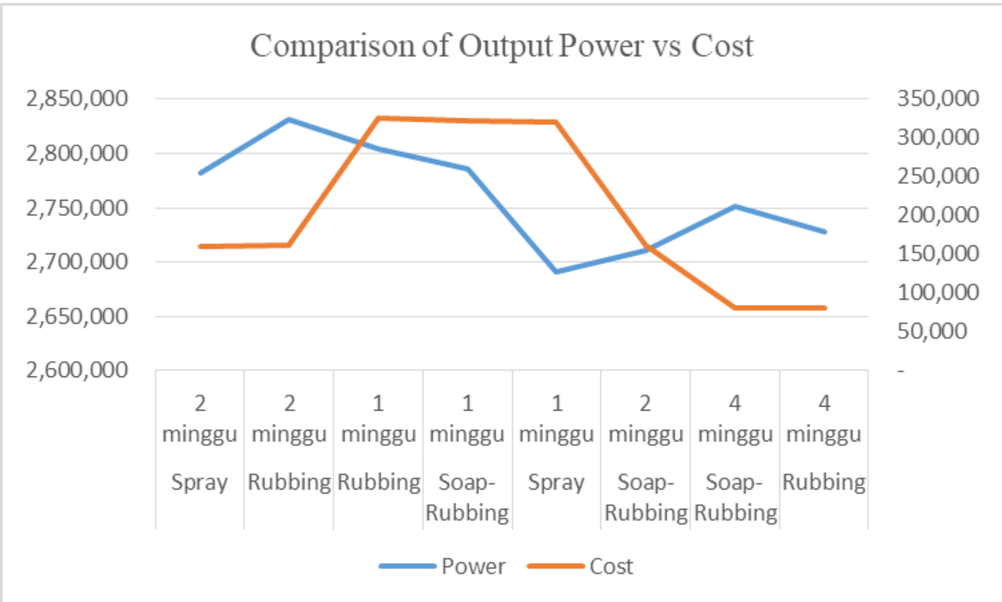

Figure 27: Comparison of Output Power vs Cost

Based on the comparison of output power and maintenance costs as shown in Figure 27, it shows that the 2-week maintenance chart has the best output power at a relatively lower cost compared to weekly maintenance which has high costs but lower power output. Whereas for 4 weeks it has the smallest cost but the power output is not optimal. If detailed on the 2-week maintenance period, it can be seen in Figure 28 that the rubbing maintenance method has optimal power output at a moderate cost compared to other maintenance methods.

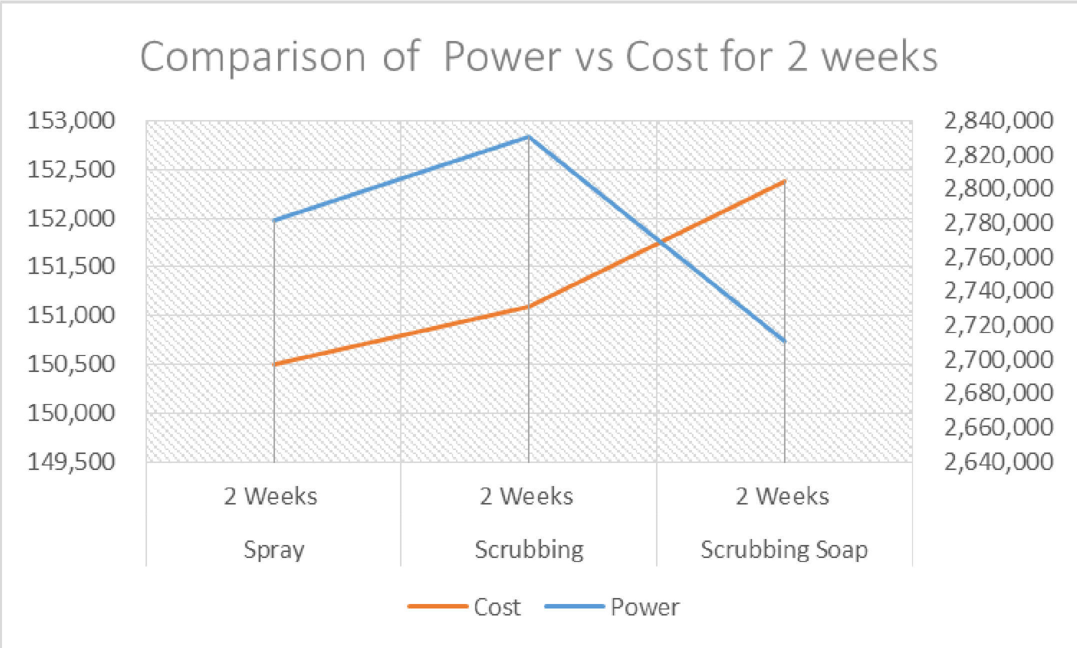

Figure 128: Comparison of Power vs Cost for 2 weeks

IV. CONCLUSION

The results showed that the most optimal maintenance method was the rubbing method with optimal time and cost maintenance in a period of 2 weeks, besides that if maintenance was carried out before entering the rainy season, the module cleanliness pattern was in accordance with previous conditions, even though the amount of output produced was smaller due to reduced radiation values. This study also shows that one of the significant factors on the output of SPP is the impact of shadows on the surface of the module.

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