Analysis of Causes ETS Generator Protection Failure Using Root Causes Failure Analysis and Root Causes Problem Solving Methods and Their Effect on the EAF Value of PLTU Anggrek

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Keywords: ETS Generator Trip, RCFA and RCPS, EAF.

Abstract: Anggrek Powerplant experienced a failure in the form of active ETS Generator Trip protection. From the results of observations on the panel, it is obtained "AVR Trip" and "Stator Earth Fault" notifications. Therefore, a system is needed to assess these problems appropriately so that when the failure occurs, it does not take too much time and costs a lot of repairs. Therefore, the author uses the RCFA (Root Causes Failure Analysis) and RCPS (Root Causes Problem Solving) methods to find the root cause and solutions to the root of the problem This paper also compares the value of EAF (Equivalent Availability Factor) PLTU Anggrek after and before doing RCFA. From the result of the failure analysis using RCFA In the AVR trip, six root causes were found, while in Earth Stator Fault there were thirteen root causes. The EAF value before doing RCFA is 74.78%, while after doing RCFA it has an EAF value of 86.31%. From the cost benefit analysis, after doing RCFA, a saving of Rp. 1,935,382,700.

1 INTRODUCTION

Anggrek Power Plant is a coal-fired steam power plant located in Ilangata village, Anggrek district, North Gorontalo district, with a production capacity of 2 x 25 MW and as a power producer to cover electricity needs in Gorontalo and North Sulawesi Provinces. In operating the PLTU Anggrek unit, it is able to reduce the basic cost of providing electricity to the North Sulawesi and Gorontalo network systems by up to 46 IDR/Kwh or 8.6 billion per month. In supporting the reliability, operation, and security of the Anggrek Power Plant unit, there is a protection system for the main equipment of Boilers, Turbines, and Generators. This is done to prevent severe damage to equipment that can cause production to stop for a long period of time and the high cost of equipment repairs that must be done.

At Anggrek Power Plant, ETS Generator Trip is a trip system that is on the generator and distribution system. This safety system will be active if a disturbance is detected in the generator and distribution equipment. On June 15, 2020, there was an active tripping ETS Generator protection at the Anggrek Power Plant, where it tripped, and the unit stopped operating. The operator tries to sync five times, but GCB (Generator Circuit Breaker) opens again. In the 1, 2, and 3 synchronization experiments on the panel, it shows the "AVR Trip" protection is active, and when the 4 and 5 synchronizations show the "Stator Earth fault" protection is active. Therefore, Anggrek Power Plant experienced a shutdown for seven days, eleven hours one minutes, and experienced a loss opportunity of 179.01 MWh.

Therefore, it is necessary to evaluate the failure in an appropriate and structured way so that it does not take up too much time, energy, and costs. RCFA (Root Causes Failure Analysis) is a step-by-step method that leads to the main cause or root cause of failure. If the cause of the failure is not found correctly, then there is a possibility that the failure will occur again and cause production losses and increased maintenance costs. RCFA is a structured method to get to the root cause, making it easier to identify the causes and symptoms that affect the problem (Zavagnin, 2008). The author also includes corrective actions using the RCPS (Root Causes Problem Solving) method, where the method has an appropriate action planning implementation based on the root of the problem. After that, the author simulates the value of EAF (Equivalent Avalability Factor) after and before doing RCFA.

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2 ANALYSIS METOD

2.1 Fault Tree Analysis

The FTA method is often used to analyze system failures. Fault Tree Analysis (FTA) is an analysis method where there is an unwanted event called an Undsired Event that occurs in the system, the system is then analyzed with existing environmental and operational conditions to find all possible ways could lead to an undesired event.

2.2 RCFA (Root Causes Failure Analysis)

Root Causes Failure Analysis (RCFA) is a failure cause analysis tool that refers to an interest in a proactive basic view that causes failure of facility equipment. The main purpose of the RCFA is to find out the cause of a problem efficiently and economically, correct the cause of the problem, not only its effectiveness, but also to fix it, and prepare data that can be useful in overcoming the problem (Wisudana, 2015).

RCFA concentrates on proactively finding the cause of failure. The difference with Failed Item Analysis is that RCFA performs proactive activities before and after a failure occurs, while Failed Item Analysis is absolute after a failure occurs. The main purpose of RCFA is to find the cause of inefficiency and uneconomical, correct the cause of failure (not only concentrate on the effect), generate enthusiasm for continuous improvement, and provide data to prevent failure. The accuracy of the RCFA results is very dependent on the perception, assumptions, depth level of logic quality and maturity of a resource person (Gulati, 2008).

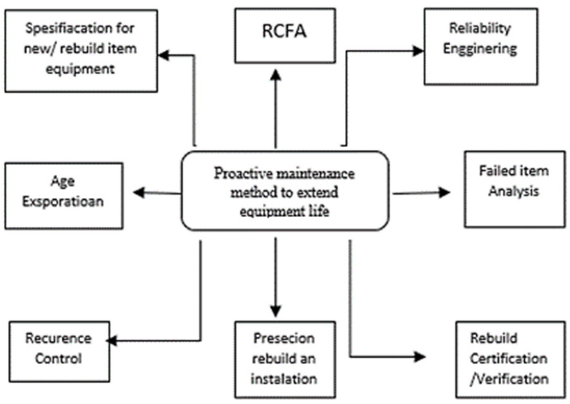


Figure 1: Proactive maintenance.

RCFA can be displayed in a variety of diagrams, including RCA Diagrams, FTA Diagrams, Ishikawa/Fishbone Diagrams, Flowchart Process and Causes mapping, and 5 Why's analysis each of which has the same perspective but differs in the focus of the problem (Gulati, 2008).

2.3 RCPS (Root Cause Problem Solving)

Root Causes Problem Solving (RCPS) is a method used to find the root cause of a problem in depth by considering all the possibilities that exist and determining the type of improvement to a problem.

Figure 2: RCPS.

2.4 EAF (Equivalent Avalability Factor)

Equivalent Availability Factor (EAF) is an indicator of the availability of power plants that have taken into account the impact of generator derating. The EAF value is a comparison obtained from the readiness of the plant to operate divided by time.

In Indonesia, EAF is used not only as a parameter of good or bad performance but also as a source of revenue for the generator itself. This is because the electricity system in Indonesia uses electricity tariffs to PLN, assessed from two things, namely EAF (Equivalent Availability Factor) and sales of electrical energy. The formula for calculating EAF is:

$$EAF = (AH - (EUDH + EPDH + EMDH + ESDH) / PH) \times 100\% \quad (1)$$

$$AH = PH - (SH + RSH) \quad (2)$$

$$SH = FOH + MOH + POH \quad (3)$$

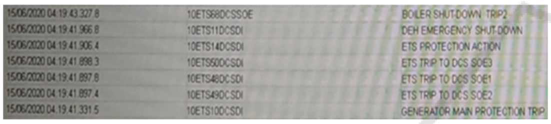
Where:
EAF = Equivalent Availability Factor (%)
AH = Availability Hours (h)
PH = Plan Hours (h)
SH = Service Hours (h)
RSH= Reverse Shutdowh Hours (h)
EUDH = Equvalent Unplaned Derating Hours
EPDH = Equivalent Planed Derating Hours
EFDH = Equivalent Forced Derating Hours

ESDH = Equivalent Schedule Derated Hours
FOH = Forced Outage Hours (h)
MOH = Maintenace Outage Hours (h)
POH = Planed Outage Hours (h)
NMC = Net Maximum Capacity

3 RESULT

3.1 Cronology of Events

On June 15, 2020 there was a failure in the form of an active ETS Generator, causing Unit 1 to Trip for 7 days 11 hours 01 minutes. This causes the PLTU Anggrek to experience a lost opportunity of 179.01 MW. Based on the information obtained from the trend data results in DCS (Distribution Control System) and field checks, the following data were obtained:



15/06/2020 04:19:43.327.8	10ETS68DCSSOE	BOILER SHUT-DOWN TRIP2
15/06/2020 04:19:41.966.8	10ETS11DCSDI	DEH EMERGENCY SHUT-DOWN
15/06/2020 04:19:41.906.4	10ETS14DCSDI	ETS PROTECTION ACTION
15/06/2020 04:19:41.898.3	10ETS50DCSDI	ETS TRIP TO DCS SOE3
15/06/2020 04:19:41.897.8	10ETS48DCSDI	ETS TRIP TO DCS SOE1
15/06/2020 04:19:41.897.4	10ETS49DCSDI	ETS TRIP TO DCS SOE2
15/06/2020 04:19:41.331.5	10ETS10DCSDI	GENERATOR MAIN PROTECTION TRIP

Figure 3: SOE units 1 Anggrek powerplant.

Based on the SOE table data, the following information is obtained:

- Generator Protection Main Protection unit 1 is active.
- ETS Trip To DCS SOE2 protection is on.
- ETS Trip To DCS SOE1 protection is on.
- ETS Trip To DCS SOE3 Protection On
- Protect ETS Protection Action
- DEH Emergency Shut-down protection is active.
- Trip2 Boiler Shut-down Protection is active

Furthermore, the data obtained from the panel display shows that the GCB is open during synchronization 6 times.

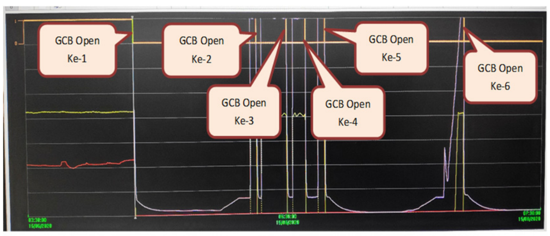


Figure 4: Trend GCB opens.

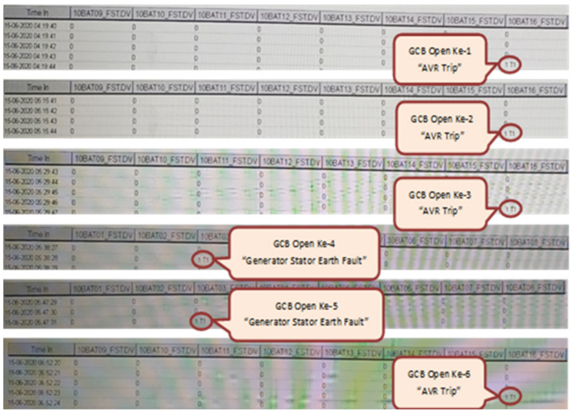


Figure 5: Trend data ETS generator protection.

Parameter / Time	GCB Open Ke-1		GCB Open Ke-2		GCB Open Ke-3		GCB Open Ke-4		GCB Open Ke-5		GCB Open Ke-6	
	4:19:40	4:19:41	5:15:41	5:15:42	5:29:43	5:29:44	5:38:27	5:38:28	5:47:29	5:47:30	6:52:20	6:52:21
Generator Power	15.71	15.48	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	2.94
#1 Generator Frequency	50.30	50.30	49.99	49.97	50.05	50.04	50.13	50.01	50.01	50.10	50.11	50.16
#1 Generator Stator Current A-B	849.56	847.42	2.60	72.09	2.60	2.60	2.60	154.64	2.60	2.60	2.60	7.14
#1 Generator Stator Current B-C	805.85	802.86	1.36	100.28	1.36	1.36	1.36	85.86	1.36	1.36	1.36	226.79
#1 Generator Stator Current C-A	869.56	866.38	2.73	85.47	2.73	2.73	2.73	94.04	2.43	2.73	2.73	2.73
#1 Generator Stator Voltage A-B	10.70	10.70	10.62	10.62	10.54	10.58	10.56	10.58	10.60	10.60	10.58	10.54
#1 Generator Stator Voltage B-C	10.71	10.71	10.60	10.63	10.52	10.52	10.54	10.60	10.58	10.61	10.56	10.56
#1 Generator Stator Voltage C-A	10.68	10.66	10.60	10.60	10.53	10.53	10.54	10.57	10.58	10.58	10.57	10.54

Figure 6: Data trend GCB opens.

In Figure 4-6, information on unit 1 data after the Generator Trip disturbance is obtained as follows:

- The first disturbance occurred at 4:19:41, which caused the GCB Unit 1 to Open.
- In the first fault, it can be seen that when the ETS protection "Generator Trip" is active, the "AVR Trip" protection generator is active at the same time (04:19:43).
- Then the operator normalized and tried again to sync at 5:15:41 but the sync failed, and GCB opened again.
- Synchronous experiments were carried out five times, but synchronous still could not be carried out. In synchronous experiments 3 and 4, GCB unit 1 opens again with the appearance of Generator Protection "Stator Earth Fault" active.

3.2 FTA (Fault Tree Analysis)

There are also results from the fault tree based on interviews with field supervisors and literature studies:

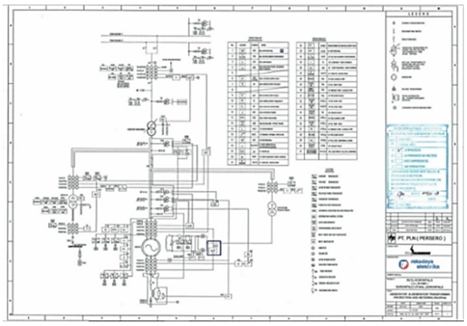


Figure 7: Generator & generator transformers protection and metering diagram.

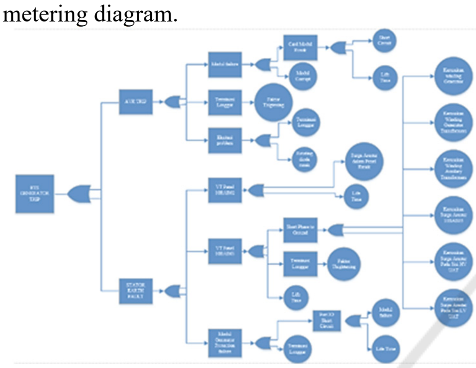


Figure 8: FTA (Fault Tree Analysis) of ETS generator trip.

3.3 RCFA (Root Cause Failure Analysis)

The results of the RCFA from the chronology of events that have been analyzed resulted in 2 main problems, namely the failure of the AVR and the grounding system so that there are notifications in the form of "AVR Trip" and "Earth Stator Fault" in the trend menu of the Generator main protection data.

1) AVR Trip

In the AVR Trip problem that appears in the 1, 2, and 3 synchronizations, there are three main root causes that were found using the Fault tree analysis method, including:

a) Module Failure

The module is a component of the AVR process in the module, and there is a card that functions as an IC or as a data processor from the field to the display. Module failure can be affected due to damage to the card module or IC module. This can happen because of the indication of a short circuit on the module and the lifetime of the module.

b) Loose Termination

A loose termination is an event where the connecting port is loose so that the data from the field is not conveyed to the display. This is a possible failure of the AVR system.

c) Excitation Problem

Excitation is a process that functions to supply direct voltage (DC) to a generator so that a generator can produce large amounts of electrical energy. This excitation process is actually the task of the AVR system, which functions as a regulator of the excitation voltage. The excitation voltage can fail because the connection between the rotating diode and the ports leading to the module is loose or even disconnected. The main thing that causes the excitation voltage problem is a damaged rotating diode. A rotating diode is the main component of creating direct voltage (DC) on the generator.

2) Earth Stator Fault

In the Earth Stator Fault problem that appears in the fourth and fifth synchronization, three main root causes were found using the Fault Tree Analysis method, including:

a) PT10BAB02

PT10BAB02 is a potential transformer that measures the current in the grounding system. From the results of the chronology, there is an error in the stator earth fault, which is also a grounding system. What can be identified is the presence of a voltage that penetrates the potential transformer PT10BAB02, which should have a safety system in the form of a surge arrester for each potential transformer. The surge arrester in the panel is damaged because the voltage penetrates to the stator earth fault or grounding system. Another possibility is the lifetime of PT10BAB02.

b) PT10BAB03

PT10BAB03 is a potential transformer that measures the voltage on the bus side of 10.5 Kv. In the chronology of events, there is network instability which causes the operator to adjust the settings of the charger tap to lower the voltage on the generator side of the transformers. Then check the PT10BAB03 potential transformers side. An active overvoltage alarm is seen. The value that is read on the indicator when the alarm is active is 120.01 V. The ratio of the potential transformer measurement is 10.5 Kv/ 100 V, which means the actual value on the Bus has a value of 12.001Kv. In fault tree analysis, overvoltage conditions can be caused by a short phase to ground or breakdown voltage on the equipment connected to PT10BAB03. From the results of the analysis, the first indication of damage or short on the winding generator, winding generator transformers, and winding auxiliary transformers. The second is damage to the protection system in the form of a surge arrester in several components that have a surge arrester and are connected to PT10BAB03 because, in the specifications, the surge arrester component is only able to receive a voltage of 12Kv. The following are the specifications for the surge arrester of the PLTU Anggrek.

Table 1: Spesifications of surge arester.

Equipment Name	Specification	
Surge Arrester	HE: 12 Ur = 12 kV Uc= 10.2 kV	Is = 20 kA F = 50/60 Hz
	Manufacture: Tridelta Varisil	

So it can be concluded that when the overvoltage condition on the 10.5 Kv line, the surge arrester contained in the connected component on the 10.5 Kv line is damaged because the maximum specification is 12Kv. The following from the analysis of the fault tree components that were damaged include damage to the surge arrester PT10BAB03, damage to the surge arrester on the HV UAT (Auxilary transformers) side, and damage to the surge arrester on the LV UAT (Auxilary Transformers) side.

The next factor that causes overvoltage is the termination of the system that is loose or not installed accurately can also cause the system to be unstable. Then the last factor is the lifetime factor of PTBAB1003 equipment.

c) Module Generator Protection Failure

The generator failure protection module is a module for safety when an error occurs in the generator. In the generator protection system there are connecting ports and modules that process data so that if the damage is detected on the generator, the module will send a command to the main system to open the 10.5Kv CB. This can be a problem due to a damaged port or a damaged module due to failure, and a lifetime can send commands to open a 10.5 Kv CB with a certain error, but the system is actually still working very well. This has happened to the PLTU Anggrek so that in the fault tree analysis, the authors review and enter the problem into the fault tree. Next is a loose termination. This can cause the system not to work according to standards and can cause errors during operation.

3.4 RCPS (Root Cause Problem Solving)

The results of the analysis of the RCPS (Root Causes Problem Solving), which is the selection of solution actions based on "5 Why's analysis" to find the right solution according to the problems that occur.

Table 2: RCPS of ETS generator trip.

Root Cause Problem Solving (RCPS)				
	Why 1	**Why 2**	**Why 3**	
AVR Trip	Modul failure	Module card is broken	Short circuit	Replacing the damaged card module with a new card module
			Life time	
		Modul Corupt		Repair the module if it can still be used by checking components
	Loose Termination	Thightening Factor		Checking or repairing connections between ports on the AVR
	Problem Excitation	Loose Termination		Check and repair between ports on connection and excitation system
		Rotating Diode is broken		Replacement of rotating diode components
Stator Earth Fault	VT Panel 10BAB02	The surge arrester inside the panel is broken		Check the surge arrester with the IR test, if the results show no voltage then the surge arrester is replaced
		life time		Change of VT Panel 10BAB02
	VT Panel 10BAB03	Short Phase to ground	Generator winding damage	Replacing the damaged component of the winding generator
			Transformers winding generator damage	Replacing the damaged components of the winding Generator transformers
			Damage to winding auxiliary transformers	Replacing the damaged Auxillary Transformers winding components
			Damage to surge arrester PT 10BAB03	Replacing a faulty surge arrester
			Damage to the surge arrester on the HV UAT	Replacing a faulty surge arrester
			Damage to surge arrester on LV side of UAT	Replacing a faulty surge arrester
		Loose termination	Thightening factor	Checking and reconnecting ports and loose connections
		life time		Change of VT Panel 10BAB03
	Modul Generator Protection failure	Port IO circuit	Modul failure	Replace the failed module
			life time	change port or connection
		Loose termination		Checking and reconnecting ports and loose connections

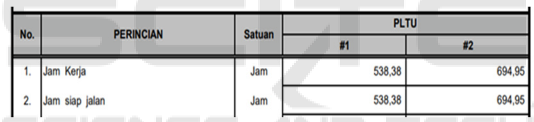
3.5 EAF (Equivalent Avalability Factor)

From the results of interviews and discussions with field supervisors, PLTU Anggrek has a work contract with PLN where the contract discusses the regulations for taking shutdown hours, where the shutdown hours are calculated daily. So in planning improvements by conducting RCFA first, it takes 4 days to work (based on interviews with field supervisors). Whereas before doing RCFA, it takes 7 days to work.

Table 3: Comparison of SH anggrek powerplant unit 1 June 2020.

Comparison of shutdown hours of PLTU Anggrek in June 2020			
No	Problem	Before doing RCFA (h)	After doing RCFA (h)
1	ETS Generator Trip	179.02	96
2	Low Vaccum Condenser	2.6	2.6
	Total	181.62	98.6

a) Calculating June EAF before doing RCFA



No.	PERINCIAN	Satuan	PLTU #1	PLTU #2
1.	Jam Kerja	Jam	538,38	694,95
2.	Jam siap jalan	Jam	538,38	694,95

Figure 9: Data for AH Anggrek powerplant for June 2020.

It is known in Figure 14 that the working hours of PLTU Anggrek Unit 1 in June are 538.38 hours, so :

EAF = (AH – (EUDH + EPDH + EMDH + ESDH) / PH) x 100%

EAF = ((538.38 -(0))/720)X 100%

EAF = 74.78% (4)

b) Calculating June EAF after doing RCFA

From table 4, the value of SH (Shutdown Hours) of Anggrek Powerplant during June 2020 is 98.8 hours. The AH (Availability Hours) value is calculated using the formula:

AH = PH-(SH+RSH)

= 720-(98.8+0)

= 621.2 (5)

Then the EAF value is:

EAF = (AH – (EUDH + EPDH + EMDH + ESDH) / PH) x 100%

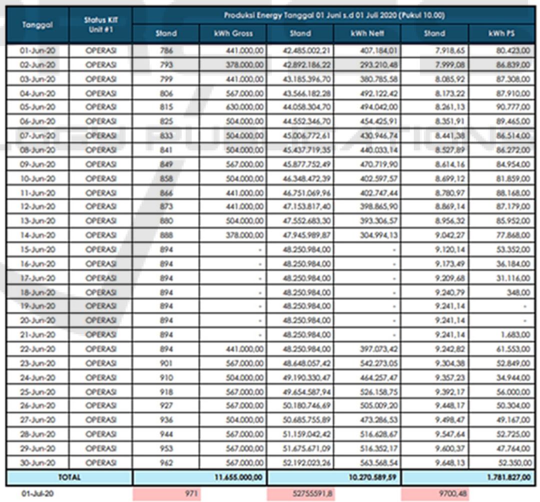
EAF=((621.2 -(0))/720)X 100%

EAF = 86.62% (6)

From the results of the EAF value of the Anggrek Powerplant in June 2020 which has been calculated, the value before doing RCFA on the ETS Generator trip problem is 74.78%, while after doing RCFA the value is 86.28%. Compiling a repair plan using RCFA can increase the EAF value by 12.1%. The EAF value after carrying out the RCFA exceeds the EAF value set by PJB as a work contact to the PLTU Anggrek, which must be above 82.72% for semester 1 (January-June), while for semester 2 (July-August), it must have a value above 71.5%.

3.6 Cost Benefit Analysis

After analyzing the EAF value, it is necessary to calculate how much profit is obtained when conducting RCFA analysis after the ETS Generator Trip event. The following is the electricity production data for unit 1 PLTU Anggrek in the month of june 2020:



Tanggal	Status KIT Unit #1	Produksi Energy Tanggal 01 Juni s.d 01 Juli 2020 (Pukul 10.00)					
		Stand	kWh Gross	Stand	kWh Neff	Stand	kWh PS
01-Jun-20	OPERASI	786	441.000,00	42.485.002,21	407.184,01	7.918,65	80.423,00
02-Jun-20	OPERASI	793	378.000,00	42.892.186,22	293.210,48	7.999,08	86.839,00
03-Jun-20	OPERASI	799	441.000,00	43.185.396,70	380.785,58	8.085,92	87.308,00
04-Jun-20	OPERASI	806	567.000,00	43.566.182,28	492.122,42	8.173,22	87.910,00
05-Jun-20	OPERASI	815	630.000,00	44.058.304,70	494.042,00	8.261,13	90.777,00
06-Jun-20	OPERASI	825	504.000,00	44.552.346,70	454.425,91	8.351,91	89.465,00
07-Jun-20	OPERASI	833	504.000,00	45.006.772,61	430.946,74	8.441,38	86.514,00
08-Jun-20	OPERASI	841	504.000,00	45.437.719,35	440.033,14	8.527,89	86.272,00
09-Jun-20	OPERASI	849	567.000,00	45.877.752,49	470.719,90	8.614,16	84.954,00
10-Jun-20	OPERASI	858	504.000,00	46.348.472,39	402.597,57	8.699,12	81.859,00
11-Jun-20	OPERASI	866	441.000,00	46.751.069,96	402.747,44	8.780,97	88.168,00
12-Jun-20	OPERASI	873	441.000,00	47.153.817,40	398.865,90	8.869,14	87.179,00
13-Jun-20	OPERASI	880	504.000,00	47.552.683,30	393.306,57	8.956,32	85.952,00
14-Jun-20	OPERASI	888	378.000,00	47.945.989,87	304.994,13	9.042,27	77.868,00
15-Jun-20	OPERASI	894	-	48.250.984,00	-	9.120,14	53.352,00
16-Jun-20	OPERASI	894	-	48.250.984,00	-	9.173,49	36.184,00
17-Jun-20	OPERASI	894	-	48.250.984,00	-	9.209,68	31.116,00
18-Jun-20	OPERASI	894	-	48.250.984,00	-	9.240,79	348,00
19-Jun-20	OPERASI	894	-	48.250.984,00	-	9.241,14	-
20-Jun-20	OPERASI	894	-	48.250.984,00	-	9.241,14	-
21-Jun-20	OPERASI	894	-	48.250.984,00	-	9.241,14	1.683,00
22-Jun-20	OPERASI	894	441.000,00	48.250.984,00	397.073,42	9.242,82	61.553,00
23-Jun-20	OPERASI	901	567.000,00	48.648.057,42	542.273,05	9.304,38	52.849,00
24-Jun-20	OPERASI	910	504.000,00	49.190.330,47	464.257,47	9.357,23	34.944,00
25-Jun-20	OPERASI	918	567.000,00	49.654.587,94	526.158,75	9.392,17	56.000,00
26-Jun-20	OPERASI	927	567.000,00	50.180.746,69	505.009,20	9.448,17	50.304,00
27-Jun-20	OPERASI	936	504.000,00	50.685.755,89	473.286,53	9.498,47	49.167,00
28-Jun-20	OPERASI	944	567.000,00	51.159.042,42	516.628,67	9.547,64	52.725,00
29-Jun-20	OPERASI	953	567.000,00	51.675.671,09	516.352,17	9.600,37	47.764,00
30-Jun-20	OPERASI	962	567.000,00	52.192.023,26	563.568,54	9.648,13	52.350,00
TOTAL			11.655.000,00		10.270.589,59		1.781.827,00
01-Jul-20		971		52755591,8		9700,48	

Figure 10: Electricity production unit 1 PLTU Anggrek in June 2020.

From the figure, the value of electricity production per day by PLTU Anggrek is obtained, which is distributed to 150 KV substations. Before doing the RCFA analysis, it is worth 10,270,598.59 Kwh. Meanwhile, the average daily production of PLTU Anggrek is 446,547.76 Kwh. Then the Powerplant income is calculated before conducting the RCFA:

Price of electricity/Kwh: Rp. 1,444.70

1 month income = 10,270,598.59 x 1,444.70

= Rp. 14,837,933,800 (7)

Meanwhile, the revenue for the PLTU Anggrek after RCFA is:

Average daily electricity production = 446,547.76 Kwh

Total production for 1 month = 10,270,598.59 + (446,547.76 x 3)

=11.610.241.9 Kwh (8)

Price of electricity/Kwh = Rp. 1.444,70

1 month income = 11.610.241,9 x 1.444.70

=Rp. 16.773.316.500 (9)

From the cost-benefit analysis, it is found that doing RCFA will increase generator income by Rp. 1,935,382,700.

4 CONCLUSIONS

1) In calculating PLTU Anggrek could not reach the target set by PJB, namely EAF in semester 1 (January-June) of 82.72%, but when have done RCFA, the EAF value has increased by 12.1% so that it is worth 86.28% and has reached the target set by PJB.

2) From the income calculation, it was found that doing RCFA at the ETS Generator Trip event was able to increase revenue by Rp. 1,935,382,700.

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