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Online Blade Washing Analysis on Gas Turbine Performance in Power Plants

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Abstract

The main problem that often occurs in the operation and maintenance of power plants is a decrease in the reliability of the gas turbine. The decline in the performance of the gas turbine, which often experiences trips, was recorded at the highest 3 times in one day. Based on the inspection, it was found that there were deposits on the compressor and turbine blades during operation. The decrease in power in the generating unit is accompanied by an increase in fuel consumption. The purpose of this study is to analyze blade washing online on the performance of gas turbines due to the formation of carbon deposits on the compressor wheel and turbine wheel. To improve the reliability of the gas engine, a method of doing blade washing is needed to clean carbon deposits in the compressor and turbine wheel. Based on the results of research before blade washing the turbine power only reached 255.37621 MW, after blade washing was able to make the compressor work more reliably, produce good turbine gas efficiency, and be able to reduce turbine gas performance disturbances due to running hours the power generated reached 268,77738 MW, there is a fuel consumption savings of 1.4 kg/s and thermal efficiency of 0.8%. Online washing is carried out at a load condition of 200MW ±5MW. To clean fouling and maintain the performance of the turbine. Cleanliness of the compressor and turbine blades can be maintained by carrying out this blade washing based on a periodic schedule calculated based on running hours.

***Keywords**: blade washing on-line; compressor & turbine wheel; turbine gas efficiency*

1. Introduction

Gas-Fired Power Plant Extension Project (GFPPEP) with a capacity of 740 MW. The power plant has a combined cycle scheme consisting of two Gas Turbines (GT) namely GT 3.1 & GT 3.2 with type and has two Heat Recovery Steam Generators (HRSG) and one Steam Turbine [1]. This GT uses natural gas fuel and produces 235 MW (at installed power) for each unit, while for backup if natural gas cannot be supplied by PT. X, it uses high-speed diesel (HSD).

PLTGU is an equipment installation that functions to convert heat energy (the result of burning fuel and air) into useful electrical energy. This PLTGU system is a combination of PLTG and PLTU [2].

PLTU utilizes heat energy and steam from exhaust gases resulting from combustion in the PLTG to heat water in the HRSG (Heat Recovery Steam Generator), so that it becomes dry saturated steam. This dry saturated steam will be used to turn the turbine blades [2].

The gas produced in the combustion chamber at the gas power plant [3] then moves the turbine blades mechanically and because of the location of the generator on one shaft with the turbine it will drive the generator [2], This mechanism will convert it into electrical energy. Similar to PLTU, PLTG fuel can be in the form of liquid

(BBM) or gas (natural gas). The use of fuel determines the level of combustion efficiency and the process [2][4].

Gas turbine generators often experience trips up to 3 times a day, this will affect the productivity of the generator. The factor of decreasing the performance of the gas turbine, due to the presence of a deposit on the surface of the compressor and turbine blades [5]. Deposits attached to the compressor blades can reduce the supply of air to the combustion chamber, and can hamper the overall performance of the gas turbine [6]. The formation of deposits on the compressor and turbine blades is due to the imperfect air to fuel ratio [7][8]. The process of deposit formation is a reaction between air-containing dust and fuel in the combustor chamber [9][10]. Polluted air contains dust, sand, hydrocarbon vapors, insects, and salt. Figure 1 describes the scheme of the generation process from the PLTU/PLTGU.

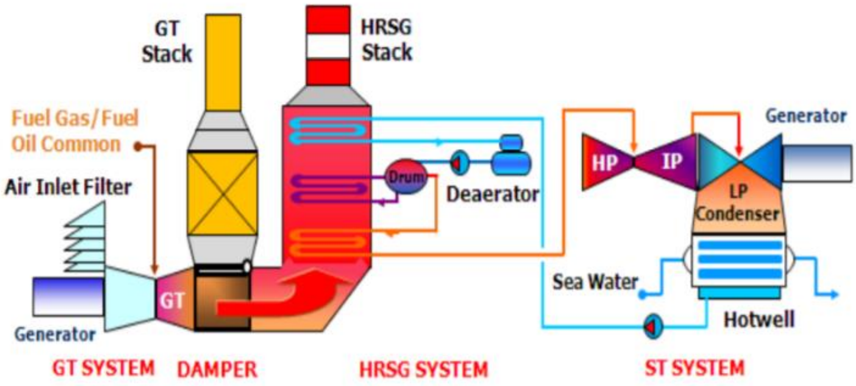

Figure 1. Gas and steam power plant process

To keep the blade compressor performance clean, it must be cleaned online or off-line, in other words, it can be carried out on the condition of the gas turbine being loaded or unloaded. The method is carried out by spraying pressurized water into the compressor blade, to reduce deposits on the blade compressor surface [11].

With the physical condition of the working environment around the gas turbine which has a risk of air contamination of 180 μg/Nm^3 (around the power plant area there is loading and unloading of sand), coal storage, and cooking oil factory) further studies need to be done to find out how much effectiveness cleaning the compressor and turbine blades have on the overall gas turbine efficiency [12]. To be a reference in finding the most optimal time in carrying out this online blade washing method [13][14].

2. METHODS

In this research, unit performance data is needed to carry out the calculation process. The data is taken and obtained from the results of observations and recordings stored in the computer system while the unit is operating [15]. 1) Compressor efficiency after cleaning blade washing on-line, 2) Gas turbine efficiency after cleaning by on-line blade washing, 3) Fuel efficiency after cleaning by on-line blade washing.

The time required for the research is 4 months (from April to July 2021), while the data for the analysis process is 15 days.

Procedures to be followed when doing online blade washing:

1. Filling the blade washing tank, the steps are taken:
   a. Operate the make-up water transfer pump,
   b. Open the water supply valve 30SDD01AA101 to fill the blade washing tank,
   c. After the blade washing tank is filled to 1000mm, close the water supply valve 30SDD01AA101 (Blade washing pump auto stop level: 260 mm).

2. Gas turbine load setting at 200MW ±5MW.
   a. Make sure the operation mode select is in the “LOAD LIMIT” position. Done to anticipate unstable network frequency.
   b. Select APR MODE "OFF".

c. *ALR SET at 200MW.*
d. Wait up to 30 minutes before performing online blade washing to stabilize the blade path temperature.

3. *On-line washing*
   a. Open valve 30SDD01AA102 (GT compressor blade washing pump suction Valve).
   b. Close valve 30SDD01AA106 (GT compressor blade washing pump min. flow orifice bypass valve).
   c. Close valve 30SDD01AA903 (GT compressor blade wash pump disc. line drain valve).
   d. Close valve 3*SDD01AA122 (GT comp blade wash water off-line supply a/b valve).
   e. Select the GT compressor blade washing pump “ON” push button in the local control panel. Make sure the pump is running and the “RUN” light is on.
   f. Make sure that “BLADE WASH AVAIL” is on the OPS.
   g. Select “ON-LINE WASH START” PB in OPS.
   h. Gently open and adjust the GT compressor blade washing pump discharge valve (3*SDD01AA103) to Pressure 5.4 kg/cm^2 (or 0.15 m3/min). Keep the valve open and pay attention to the Pressure Indicator because if there is too much water flow it will cause the unit to trip.
   i. Make sure that the GT online washing water supply valve (3*SDD01AA702) is locally open.
   j. Water wash time for 3 minutes, pay attention to the blade path temperature.
   k. Select “OFF” PB in OPS.
   l. Make sure that the GT online washing water supply valve (3*SDD01AA702) is closed locally.
   m. Close the valve GT compressor blade washing pump discharge valve (3*SDD01AA103).
   n. Perform the steps (g m) up to 3 (three) times, with a pause of 10 minutes.
   o. *Stop GT compressor blade washing pump when finished.*.
   p. Hold gas turbine load at 200MW for 30 minutes.

4. Restoration
   a. After the GT compressor blade washing pump stops, open the GT compressor blade washing drain valves (30SDD01AA901, 902). Do not let any water remain in the pipeline for a long time.
   b. Close the GT compressor blade washing drain valves (30SDD01AA901, 902) after the remaining water is used up.
   c. Close valve 30SDD01AA102 (GT compressor blade washing pump suction valve).
   d. Open valve 30SDD01AA106 (GT compressor blade washing pump min. flow orifice bypass valve).
   e. Open valve 30SDD01AA903 (GT compressor blade wash pump disch. line drain valve).
   f. Open valve 3*SDD01AA122 (GT comp blade wash water off-line supply a/b valve).

A literature study is used to obtain steps or formulas for the calculation process. Calculations were carried out according to the data obtained during observations and using formulas obtained from the literature. The results of this calculation will then be presented in the form of tables and graphs. This discussion contains the analysis of the results that have been obtained from the calculations that have been carried out. The conclusion is a final summary containing the results of the analysis, under with the research objectives. Gas turbine technical data and specifications:

Manufacturer	: X
Model	: M701F, single shaft

Rate output	: 270 MW
Efficiency	: 38,2 %
Type	: axial flow type
Fuel	: Natural gas
No. of stages	: 4
Turbine inlet temperature	: 1400°C
Operating air temperature	: 21,6°C – 35,5°C
Max Loading rate	: 6,7%/min
Speed increase rate	: 135 rpm/min
Combustion chamber	: 20 pcs, multi-can annular type
Generator	: 315 MVA
Frequency	: 50 Hz
Power factor	: 0,85
Speed	: 3000 rpm

Compressor

Type	: Axial flow type
No. of stages	: 17
Air flow	: 651 kg/s
Inlet air filter type	: Static pressure

Data retrieval is taken based on the results of several graphic forms that are stored in the OPS (operator station) memory continuously while the unit is operating.

3. Result and Discussion

Table 1 describes the composition of the gas used for power generation. It is known that the fuel supplied from offshore PHE is natural gas with its composition and tabulated.

Table 1. Consumption of gas fuel (PHE)

Description	Xi (mixture) mol (%)	Mi (molal mass) kg/kmol	BMf kg/kmol
Carbon Dioxide, CO2	5.00	44.01	2.2005
Nitrogen, N2	0.61	28.02	0.170922
Methane, CH4	84.50	16.043	13.556335
Ethane, C2H6	4.91	30.07	1.476437
Propane, C3H8	2.88	44.097	1.2699936
ISOButane, iC4	0.79	58.124	0.4591796
N-Butane, nC4	0.60	58.124	0.348744
ISOPentane, iC5	0.27	72.151	0.1948077
N-Pentane, nC5	0.17	72.151	0.1226567
Hexane, C6	0.15	86.178	0.129267
heptane plus, C7+	0.12	100.2	0.12024
	Total		20.0490826

Lower calorific value (Low Heating Value) of fuel.

$$Calorific\ value\ (LHV)\ = 1115{,}6619\,\frac{BTU}{SCF}$$

$$because:\ 1\ BTU\ = 1{,}0551\ KJ,\ and\ 1\ m^3\ = 35{,}315\ ft^3$$

$$Calorific\ value\ (LHV)\ = 1115{,}6619 \times 1{,}0551 \times 35{,}315 = 41570{,}51796\ \left(\frac{kJ}{m^3}\right)$$

The calorific value of fuel at the condition of entering the combustion chamber per unit volume**.**

$$LHV_V = LHV\left(\frac{P_2 \times T_1}{P_1 \times T_f}\right) \quad (1)$$

$$= 41570.51796\ \frac{kJ}{m^3}\left(\frac{14{,}4 \times 303{,}6}{1{,}0286 \times 473{,}2}\right)$$

$$= 373384.8790\ \frac{kJ}{m^3}$$

Gravimetric combustion value (LHV_m).

$$LHV_m = LHV_V \times v \quad (2)$$

$$= LHV_V\left(\frac{R_o \times T_f}{BMf \times P_2}\right) \quad (3)$$

$$= 373384.8790\ \frac{kJ}{m^3}\left(\frac{1{,}16444\ J/kmol \times 473{,}2\ ^\circ K}{20{,}049\ kg/kmol \times 1412640\ N/m^2}\right)$$

$$= 51866.53878\ \ kJ/kg$$

Energy enters the system (Q_{in})

$$Q_{in} = \dot{m}_f \times LHV_m \quad (4)$$

$$\dot{m}_f = 65{,}613\ BBTU = 2733{,}859949\ MMBTUH$$

$$1MMBTUH = 27{,}49\ \frac{m^3}{h},$$

$$\rho_{natural\ gas} = 0{,}9\ \frac{kg}{m^3}\ (table\ Densities\ of\ Gas)$$

$$\dot{m}_f = 2733{,}859949 \times 27{,}49 \times 0{,}9\ \left[\frac{kg}{jam}\right]$$

$$= 67638{,}42899\ \frac{kg}{jam} = 18{,}79\ \frac{kg}{s}$$

$$Q_{in} = 18{,}79\ \frac{kg}{s} \times 2733{,}859949\ \frac{kJ}{kg}$$

$$Qin = 976220\ kJ/s = 976.22\ \text{MW}$$

By using the same method, the calculation results will be obtained as shown in Table 2.

Table 2. Qin GT 3.1

NO	T1	Mf	LHV		LHVv	LHVm	Qin
	K	kg/s	BTU/SCF	kJ/m3	kJ/m3	kJ/kg	MW
1	303,60	18,79	1.115,66	41.570,52	373.384,88	51.866,54	976,22
2	305,20	17,38	1.116,96	41.619,06	378.580,65	52.214,56	916,49
3	302,40	18,04	1.118,01	41.658,16	375.053,31	51.749,93	942,58
4	301,70	18,10	1.117,55	41.640,81	374.989,66	51.697,42	943,80
5	302,40	17,90	1.115,80	41.575,55	375.399,72	51.743,01	935,17
6	306,10	17,44	1.107,61	41.270,46	374.296,02	51.971,13	910,21
7	305,30	18,60	1.113,18	41.478,20	352.033,98	52.116,91	973,33
8	305,70	17,57	1.117,99	41.657,17	385.374,11	52.417,30	920,56
9	305,70	17,55	1.118,82	41.688,31	385.376,63	52.428,72	921,74
10	305,10	17,98	1.119,79	41.724,33	384.973,03	52.384,89	941,88
11	306,40	17,91	1.120,19	41.739,21	386.700,11	52.619,90	941,57
12	304,80	18,68	1.100,65	41.011,01	369.805,72	51.391,07	960,62
13	306,70	19,09	1.053,66	39.260,35	356.311,04	49.484,37	946,56
14	300,60	23,28	1.048,58	39.070,82	280.755,32	48.132,44	1.135,52
15	305,30	19,77	1.048,70	39.075,62	355.373,24	49.013,75	972,41

Stoichiometric mixed air requirements (100%)
[A/F]*th,m,d* or ' *air to fuel ratio* ' *theoretical gravimetric, dry is***:**

$$\left|\frac{A}{F}\right|_{th,mol,d} = \frac{\mathrm{Zc} + 0{,}25.\mathrm{ZH} + \mathrm{Zs} - 0{,}5.\mathrm{Zo}}{0{,}21}\, x\, \frac{28{,}97}{BMf}$$

Calculated Zc, ZH, Zs, Zo dan ZN as follows:

$$Zc = 0.05(1) + 0.845(1) + 0.0491(2) + 0.0288(3) + 0.0079(4) + 0.006(4) + 0.0027(5) + 0.0017(5) + 0.0015(6) + 0.0012(7)$$

$$Zc = 1.1746 \text{ moles of carbon atoms per mole}$$

$$ZH = 0.845(4) + 0.0491(6) + 0.0288(8) + 0.0079(10) + 0.006(10) + 0.0027(12) + 0.0017(12) + 0.005(14) + 0.0012(16)$$

$$= 4.137 \text{ moles of hydrogen atoms per mole}$$

$$ZS = 0$$

$$ZO = 0.005(2) = 0.1 \text{ moles of oxygen atoms per mole}$$

$$ZN = 0.0061(2) = 0.0146 \text{ moles of nitrogen atoms per mole}$$

Air to fuel ratio theoretical, molar, dry or [A/F]th, mol, d:

$$\left|\frac{A}{F}\right|_{th,mol,d} = \frac{1{,}1746 + 0{,}25\,(4{,}137) + 0 - 0{,}5(0{,}1)}{0{,}21}$$

$$= 10{,}280 \text{ moles of air / moles of fuel}$$

Air to fuel ratio theoretical, mass, dry:

$$\left|\frac{A}{F}\right|_{th,m,d} = \left|\frac{A}{F}\right|_{th,mol,d} x \frac{28{,}97}{BMf}$$

$$= 10{,}280 \text{ x } (28{,}97/20{,}049) \text{ Kg of air/Kg of fuel}$$

$$= 14{,}854 \text{ kg.u/kg.bb}$$

A. Mass flow rate of air

Figure 1 is the flow of air and fuel entering the combustion chamber in the gas turbine.

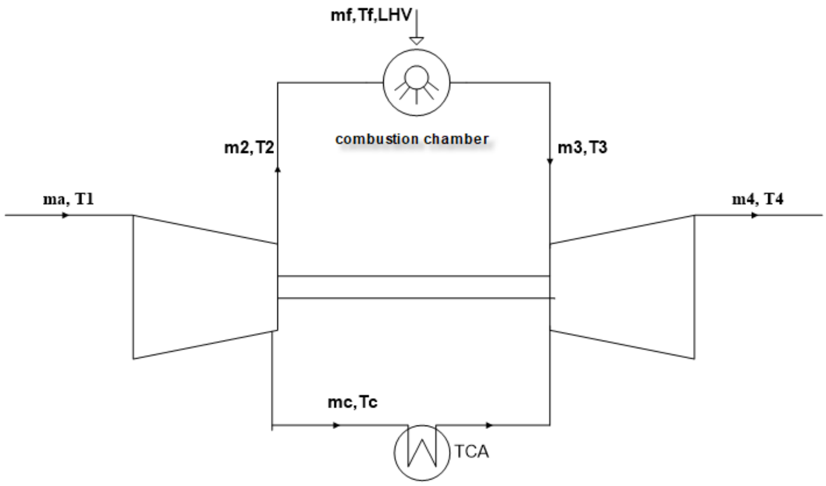

Figure 1. Air, gas and fuel flow chart

It is known from the manual book that the mass flow rate in an open cycle condition with 100% load is 2.188.300 kg/h = 607.861 (at T1 = 30°C). So for T1 = 30.6°C, m1 = 617.153 kg/s (calculated based on the ratio and the density of air).

T1 : 30,6°C = 303,6 K
m1 = ma : 617,153 kg/s
mc : 47,24 kg/s
T2 : 713,6K
m2 = m1 – mc : 569,9132 kg/s
TIT : 1400 ˚C *(MHI manual book)*
mf : 18,7885 kg/s
T3 : 1673,15K
m3 = m2 + mf : mgp
= 588,7016525 kg/s
T4 : 864,4K
m4 = m3 + mc : 635.941 kg/s

B. Actual ratio, dry air per mass of fuel

Mass ratio, actual, dry air/fuel mass

$[A/F]_{act,m,d}$ = m2 / mf = (569,9132 kg.u/s) / (18,7885 kg.bb/s)
= 30,33316342 Kg air/kg fuel

Molar ratio, actual, dry air/fuel mass:

$$\left[\frac{A}{F}\right] \text{act, mol, d} = \frac{[A/F]\text{act,m,d}}{BM\ air/BM\ fuel} \tag{5}$$

$$= \frac{30{,}33316342}{\frac{28{,}97}{20{,}049}}$$

$$= 20{,}9923 \text{ kmol air / kmol}$$

Mass ratio of fuel / air mass

$$f = \frac{1}{\left[\frac{A}{F}\right] \text{act, m, d}} = \frac{1}{30{,}33316342} = 0{,}032967218\ kg.\frac{bb}{kg}.u$$

C. Percentage of excess air (excess air)
Percentage of excess air = 100. (DC – 1), where DC = dilute coefficient

$$\text{DC} = \frac{[A/F]\text{actual}}{[A/F]\text{theoretical}} = \frac{30{,}33316342 \text{ kgu/kgbb}}{14{,}854\ kgu/kgbb} = 2{,}042$$

Then % excess air (*excess air*) = 100 (2,042– 1) = 104,209%.

So with (%) excess air of 104,209%, this means that the actual air requirement for the combustion process is 2,042 times the minimum theoretical air requirement, or 204% theoretical air is required.

D. Compressor cycle calculation

Actual compressor work per mass rate (Wkm)

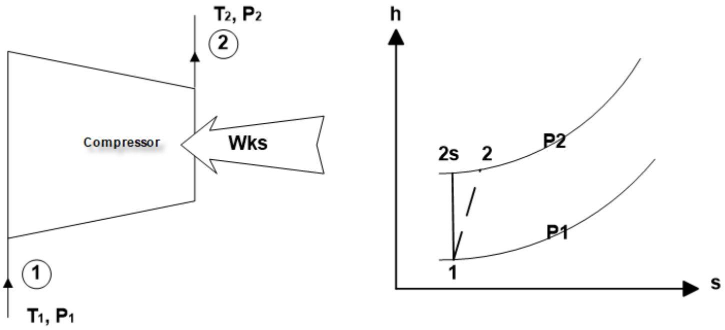

Figure 2. Compressor working process.

$$\frac{W_K}{m} = (h_2 - h_1) \tag{6}$$

$$T_1 = 30{,}6\ ^\circ\text{C} = 303{,}6\ \text{K}$$

$$so:\ h_1 = 303{,}8116\ \frac{\text{kJ}}{\text{kg}}\ (table\ A-17)$$

$$T_2 = 440{,}6\ ^\circ\text{C} = 713{,}6\ \text{K}$$

$$so:\ h_2 = 727{,}9208\ \frac{\text{kJ}}{\text{kg}}\ (table\ A-17)$$

$$\frac{W_K}{m} = \left(727{,}9208\ \frac{\text{kJ}}{\text{kg}} - 303{,}8116\ \frac{\text{kJ}}{\text{kg}}\right)$$

$$\frac{W_K}{m} = 424{,}1092\ \frac{\text{kJ}}{\text{kg}}$$

Calculation CP_a: specific heat of air at constant pressure kJ/kg.K

At $CP_a = 0.997 - 1.022 \frac{kJ}{kg}.K$

The commonly used CP_a yang umum digunakan 1.005 kJ/kg.K = 101.325 kPa

However, in this calculation, CP_a uses 1.00926 kJ/kg.K

Actual compressor power (P_K)

$$Pk = ma \times CP_a(T_2 - T_1) \quad (7)$$

$$= (617.1532 \frac{kg}{s} \times 1.00926 \frac{kJ}{KgK}) \times (713.6 - 303.6)K$$

$$= 255.37621 \text{ kJ/s}$$

$$= 255{,}37621 \text{ Megawatt}$$

E. Enthalpy of combustion in the combustion chamber

For 204% theoretical air, the air temperature rise ΔT_{23} = 809 K. Because [A/F]m = ($1/f$) = 30.33316342 kg.u/kg.bb or the actual combustion air requirement is 204% times the theoretical mixture, meaning [1+(1/30.33316342)] = 1,0329672 kg.gp/kg.u. The gas enthalpy from combustion is obtained from "Table A.3 Products theoretical air" with 200% and 400% theoretical air. The molar enthalpy at temperature

T3 = 1673,15 K (200% and 400%):

$\hat{h}_{3,200\%}$ = 1889,022 kJ/kg (*interpolasi*)

$\hat{h}_{3,400\%}$ = 1846,468 kJ/kg (*interpolasi*)

For the molar enthalpy T3 at 204%:

$\hat{h}_{3,204\%}$ = 1866,46838 kJ/kg (*interpolasi*)

In the same way for T4 : $\hat{h}_{4,204\%}$= 916,144 kJ/kg

Heat supplied

$Q_{204\%}$ = $(1+f)$ $h\hat{i}_{3,204\%}$ - h_2

= [(1,0329672) (1866,46838) – 727,9208]

= 1235.452512 kJ/kg.u

Specific heat of product gas (Cp_{gp})

Is known:

ΔT_{23} = 809°K

$Q_{204\%}$ = 1235,452512 KJ/Kg.u

$(1+f)$ = 1,0329672 kg.gp/Kg.u

h3 – h2 = [$(1+f)$ (Cp_{gp}) (T_3-T_2)] = 945,079 kJ/Kg.u

So the specific heat of the product gas Cp_{gp} for theoretical air 204% is:

$$Cp_{gp} = \frac{1235{,}452125}{1{,}0329672 \text{ x } 945{,}079} = 1{,}270655266 \; kJ/kg_{gp}°K$$

F. Turbine cycle calculation

Actual work per mass rate (W_T/m)

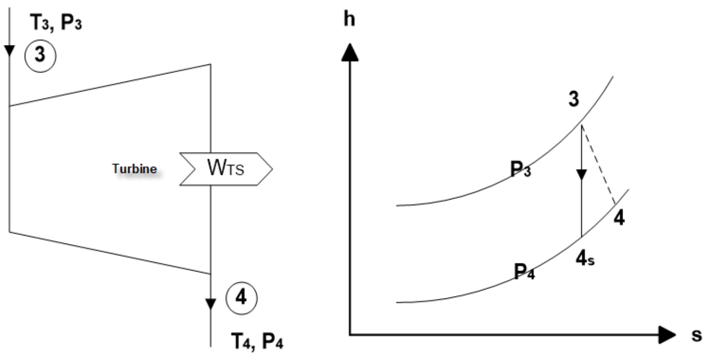

Figure 3. Turbine work per mass rate

$$\frac{W_T}{m} = (h_3 - h_4) \quad (8)$$
$$= \hat{h}_{3,204\%} - \hat{h}_{4,204\%}$$
$$= (1866{,}648 - 916{,}144) kJ/kg$$
$$= 1012{,}66 kJ/kg$$

Actual turbine power (P_T)

$$P_T = mgp.Cpgp\,(T_3 - T_4) \quad (9)$$
$$= \left(588{,}7016525\frac{kg}{s}\right).\left(1{,}270655266\frac{kJ}{kg}.K\right).(1673{,}15 - 864.4\ K)$$
$$= 604862{,}6006\ kJ/s$$
$$= 604{,}8626006\ MW$$

G. Calculation of gas turbine thermal efficiency (η_{th})

$$\eta_{th} = \frac{P_{net}}{Q_{in}} = \frac{P_T - P_K}{Q_{in}} \quad (10)$$
$$= \frac{mg\,Cp_{gp}(T3-T4) - ma\,Cp_a(T2-T1)}{Q_{in}} \quad (11)$$
$$= \frac{604{,}8626006\ MW - 255{,}37621\ MW}{974{,}492\ MW}$$
$$= 0{,}3586\ Megawatt$$
$$= 35{,}86\%$$

By using the same method, the calculation results will be obtained as shown in table 3, in table 3 this is taken for 15 days.

Table 3. Thermal efficiency calculation results

NO	T1	PT	Pk	Pnet	Qin	ηth
	°C	MW	MW	MW	MW	%
1	30,6	604,8626	255.3762	350,510	976,2190	35,86
2	32,2	602,1951	268.7774	339,4774	916,4863	36,73
3	29,4	609,7126	267.2738	352,7663	942,5788	36,68
4	28,7	608,0405	265.7236	352,4559	943,8018	36,59
5	29,4	606,3278	266.8612	350,2702	935,1695	36,65
6	33,1	594,2965	264.9837	340,1773	910,2068	36,33
7	32,3	615,3465	262.9029	371,0327	973,3323	36,36
8	32,7	592,2283	259.7237	334,7549	920,5555	36,10
9	32,7	596,0175	263.8237	339,6523	921,7365	36,11
10	32,1	595,7878	257.2764	338,6659	941,8793	35,95
11	33,4	592,8049	255.7238	336,3591	941,5674	35,77
12	31,8	598,7885	254.2129	344,1901	960,6232	35,90
13	33,7	593,7196	254.6623	326,8501	946,5586	35,89
14	27,6	660,9847	254.9239	432,4037	1135,517	36,23
15	32,3	600,3166	253.2623	345,2760	972,4134	35,82

H. Effect of online blade washing on Pk (compressor work GT 3.1).

Based on the data in Table 3, a graph of the relationship between compressor work and time (day) can be obtained as shown in Figure 4.

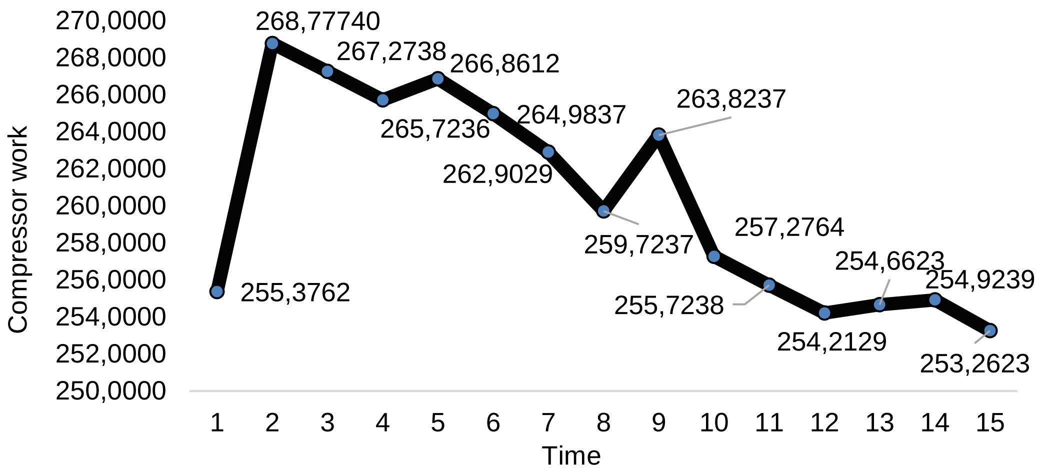

Figure 4. Compressor working graph AND Time (day)

From the calculation data shown in Figure 5, it shows that there is an increase in compressor work after on-line blade washing (points 1-2). And there is a tendency for compressor work to decrease in the following days.

I. The effect of online blade washing on fuel consumption

The data in table 3 can also produce a graph of the relationship between fuel consumption and time (day) as shown in Figure 5.

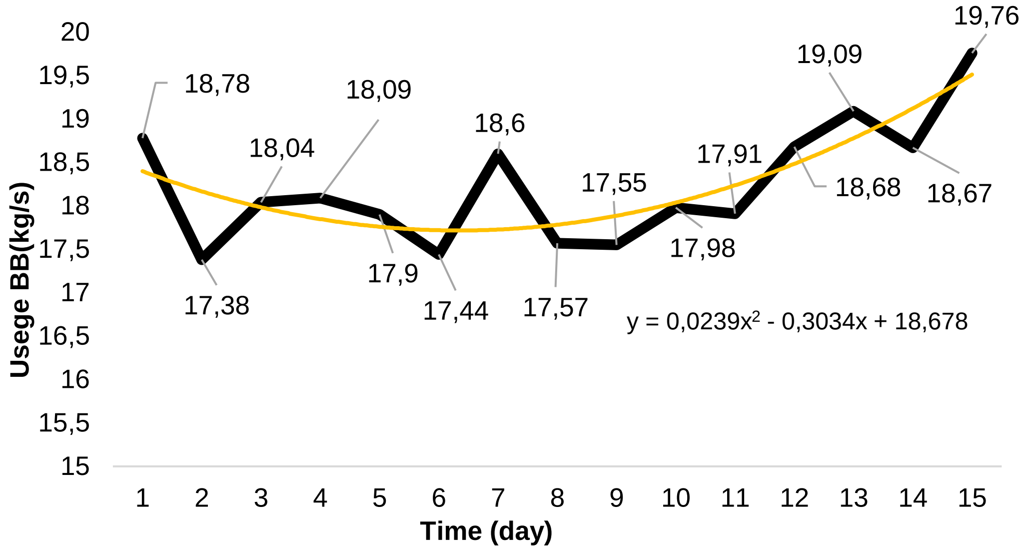

Figure 5. Graph of fuel consumption and time (day)

In the trendline of Figure 5, it can be seen that after blade washing there is a fuel consumption savings of around 1.4 kg/s (points 1-2), then an increasing trend of fuel consumption can be seen in the following days.

J. Effect of online blade washing on thermal efficiency (ηTh)

The relationship between compressor intake air temperature and thermal efficiency can be seen in Figure 6 (based on table data 3).

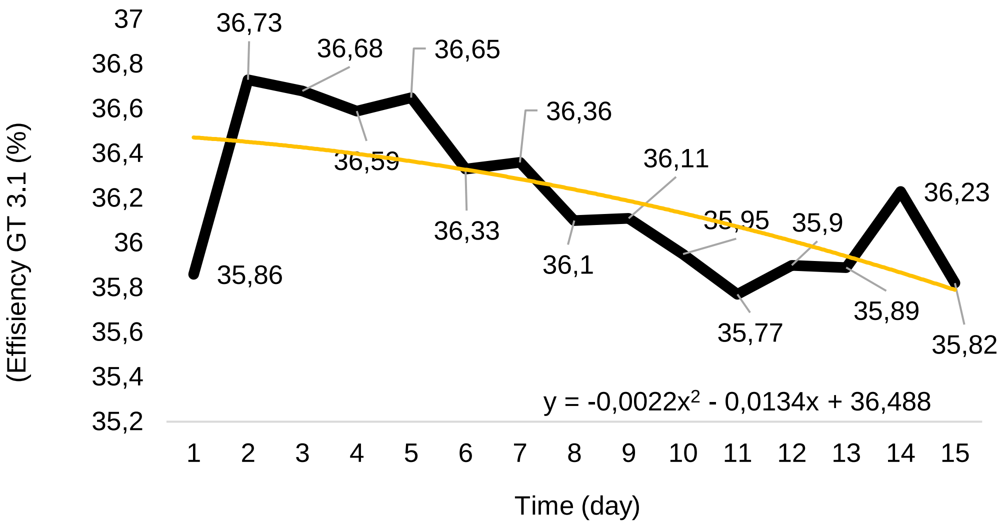

Figure 6. Graph of thermal and time (day) GT efficiency

Figure 6 shows the change in thermal efficiency with time, which is shown in the black line. While the yellow line shows the trend line which clarifies the increase in thermal efficiency after blade washing (points 1-2) on the graph is ±0.8%. From the graph in Figure 6 online blade washing can maintain optimal GT performance, and will reduce the steep decline in GT performance when done regularly

4. Conclusion

After calculating and analyzing, it can be concluded that 1) Cleaning the compressor blades using the online blade washing method can improve compressor performance on gas turbines, as indicated by the GT output power reaching 268,77738 MW and fuel savings of 1.4 kg/s. 2) Regularly doing online blade washing can improve GT performance with running hours until the next B Inspection (8000 hours) with an efficiency of 0.8%. In implementing online blade washing, it is made in the 52 Weekly plan so that the PIC is monitored and clear.

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