Energy Auditing at Block 1 Muara Karang Combined Cycle Power Plant

Andy Setyanto[1], Ary Bachtiar Krishna Putra[1]

***Abstract*—Every year electricity growth in the world always increases. But the growing growth is the need for future controls in order to make the utilization more effective and efficient. In addition, with the utilization of appropriate energy will have an impact on the preservation of the surrounding environment. In Indonesia, has been regulated related to the efficient utilization of energy by the enactment of Government Regulation No 70 of 2009 of Energy Conservation. The method used for this research is to conduct an energy audit on PLTGU Block 1 Combined Cycle Power Plant (CCPP) Muara Karang. This audit is begin from collecting operating parameters' data then conducting the performance calculation of the main equipment. The result of the calculation then compared with commissioning data in 1995. From the calculation obtained the profile of energy use and find the largest gap from the comparison between actual performance with commissioning in 1995. The gap is then analyzed the cause of equipment inefficiency and conducted field study. After that is given the recommendation of Energy Saving Potential to be able to improve the efficiency of the equipment. The recommendations are analyzed by economic studies to provide alternative improvements solution for management.**

***Keywords*— Efficiency, Energy, Energy Audit, Energy Saving Potential, Performance**

I. INTRODUCTION

Every year electricity growth in the world always increases. This increase in line with the increased in the number of the population in a country. The energy demand world wide especially in the developing countries is growing very significantly as results of economic growth, industrial expansion, high population growth, and urbanization. Combined cycle power plants play a major role in meeting this ever increasing demand. The power cycles are investigated with an overall objective of providing high fuel conversion efficiency [1].

An energy audit is a study of a plant or facility to determine how and where energy is used and to identify methods for energy savings. There is now a universal recognition of the fact that new technologies and much greater use of some that already exist provide the most hopeful prospects for the future. The opportunities lie in the use of existing renewable energy technologies, greater efforts at energy efficiency and the dissemination of these technologies and option [2].

Many literature has often conducted at Combined Cycle Power Plant and Thermal Power plant. Both, it has own their way to give recommendation in order to increase the efficiency of plant and lowering heat rate. In this project is analysed which one of the main equipment in the power plant by conducting actual performance test. Result of that performance test than compared to commissioning data in 1995. Then it can be compiled with all main equipment and obtain the performance gap. After that, is identified which one of main equipment that spend more energy.

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Next step is giving some recommendations and possible action to conserve the energy and also would be to prioritize for their implementation.

Energy audit is a technique for identifying energy losses, quantifying them, estimating conservation potential, evolving technological options for conservation and evaluating techno economics for the measure suggested in reducing their energy consumption [3].

The objective of energy auditing is to find out the different ways to reduce the energy consumption in different fields by elucidating the losses at various stages. An energy audit can be classified into the following two types [4].

A. Preliminary Audit

Preliminary Audit is audit that find out all information about the plant and identify the major energy consumption area in the plant by using energy meter. Estimating the scope for saving and identify the most likely (and the easiest areas for take more attention) and also identify immediate (especially no-/low-cost) improvements/ savings prior to conducting detailed measurement.

B. Detailed Audit

Detailed energy audit is conducted after the preliminary energy audit. This audit giving most accurate estimate of energy savings, cost and also engineering recommendations because it effectively evaluates all major energy using systems. Moreover, it giving most accurate estimate of energy savings, cost and also engineering recommendations. Approximately 95% of all energy is accounted for during the detailed audit.

II. METHOD

Many kind of energy audit steps that used to know the pattern of energy consumption on their system. In this project using step as guidance to conduct energy auditing step by step which can be seen in Figure 1.

Energy audit object was conducted at 3x100MW Combined Cycle Power Plant (CCPP) block 1 PLTGU Muara Karang and carried out on 100% MCR (baseload). This plant consist of three Gas Turbine, three HSRG with two pressure and one Steam Turbine. Using principles of thermodynamic that mass and energy must be balance between input and output. It must be determined which system that will be analyzed. For further calculation, it can be described the control volume of system at Muara Karang Combined Cycle Power Plant in Figure 2.

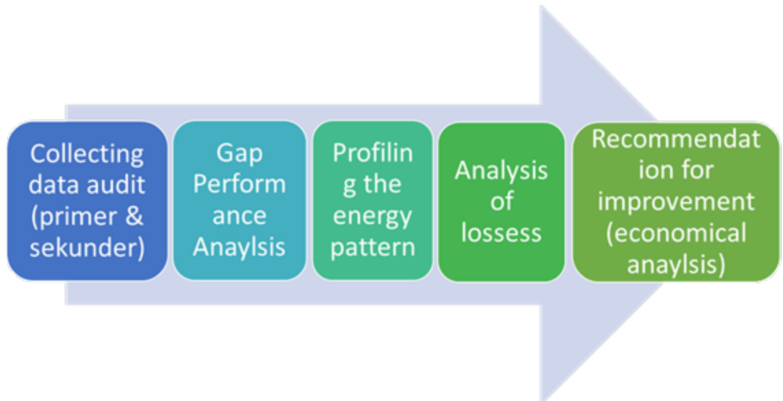

Figure 1. Energy Auditing Guidance flow chart.

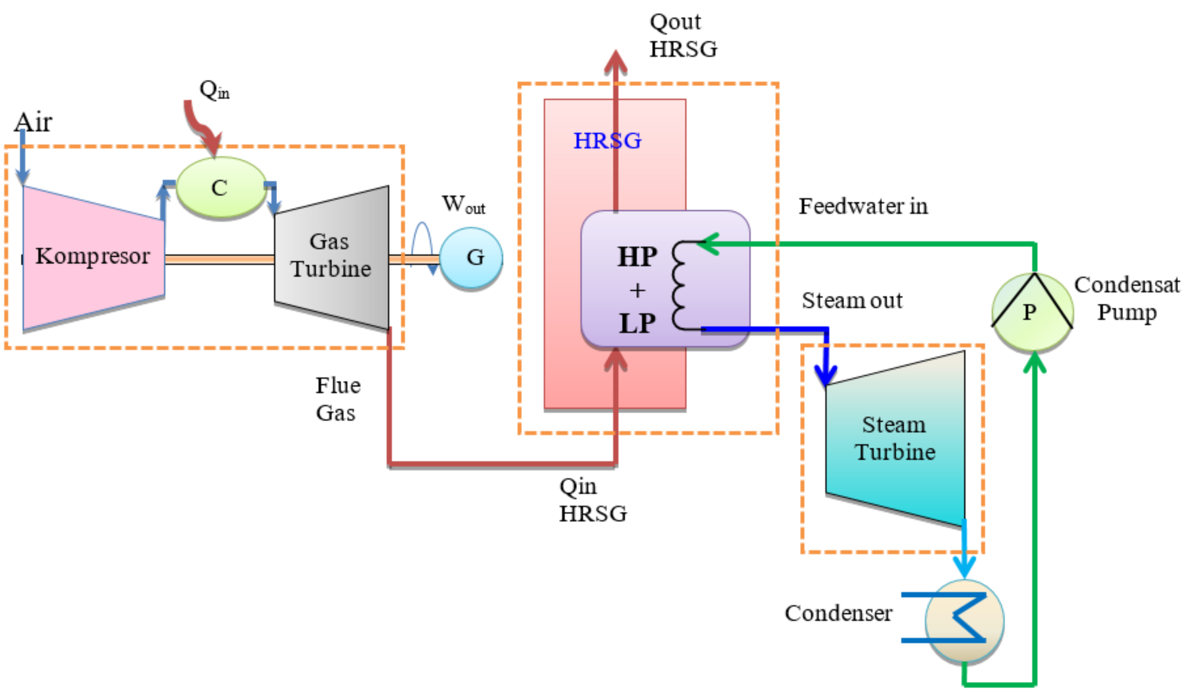

Figure 2. Schematic Diagram and system of CCPP Muara Karang

There are a lot of research that using energy auditing to know exactly what the real (actual) of power plant condition such as heat rate, efficiency, etc compared within commissioning condition. Each research has their own target and also scope of audit object as result of the auditing output and recommendation for improvement. Nevertheless, they are using same method in their process. Here is several previous research that using energy auditing:

A. Audit Energy Detailed at Thermal Power Plant[2]

Audit was conducted at thermal power plant in India with installed capacity 2x25 MW. This audit refer to ASTM PTC and CEA for conducting the energy audit. This audit focused in several equipment such as Condesate Extraction, Boiler Feed Pump Cooling Water Pump, Side Stream pump, ACW pump, CT Makeup pump, Ash Handling Plant, Compressor, HVAC, Transformer and also the lighting. As the result of this audit are:

1. Modification of WHRB FD Fan and suggest to install VFD.
2. Minimize pressure drop in condensate line (TG1 & TG2).
3. Minimize pressure drop along of FCS in feed water circuit.
4. Lowering temperature setting in the hopper heater thermostatic control.
5. Adjusting transformer lamp to decrease a number of lighting energy.

B. Audit Energy Detailed at Thermal Power Plant : Case Study [5]

This audit was performed by case study at Panipat Thermal power plant in India. Audit has passed 3 (three) stage: Pre Audit, Audit dan Post Audit stage. Then collecting all operation parameter that obtained from performance test of boiler using Indirect Method and also mapping for all losses that happened in boiler. The losses can be shown in the Figure 3.

Figure 3. Lossess in Boiler of India Thermal Power Plant using sankey diagram

The result of this audit are:

1. Improving MS pressure by improving control system so heat reat will be increase about 13,29 kJ/kWh with cost of Rs. 1,02,29,233.
2. Improving HRH temperature by improving control system so heat reat will be increase about 22,18 kJ/kWh with cost of Rs.1,70,38,114.
3. Improving vacuum by improving control system of ejector so heat reat will be increase about 17,72kJ/kWh.
4. Improving the insulation by repaired insulation of damaged area

C. Audit Energy Detailed at Thermal Power Plant [6]

Audit was performed at GURU HARGOBIND THERMAL PLANT with focus on load and operation and distributin. Load is measured at 100% MCR load in 29 Desember 1997 with installed capacity 210 MW. Then perform performance calculations on the existing operating data and the resultsin Table 2.

Table 3 shown conclude for lossess that actually happened in the boiler. In the other hand was conclude to for other auxillary boiler such as Air Preheater, Furnace, Turbine dan Condenser.

TABLE 1.
ENERGY OPTION FOR UNIT 7 PLANT

S.I No.	**Improve Effiency**	**Energy Saving**			**Financial Saving @15000 per TOE in Rs**	**Investment in Rs.**	**Pay Back Period in Month**
A	**Turbine Heat Rate**	**Turbine cycle Heat Rate Improvement on kJ/kWh**	**Energy Saving in kJ/Year**	**Annual TOE saving in TOE/Year**			
1	Improving Main Steam Temp.	13.29	2.91×10^{10}	681.95	1,02,29,322	Nil	Immediate
2	Improving HRH Steam Temp.	22.18	4.85×10^{10}	1135.37	1,70,38,14	Nil	Immediate
3	Improving condenser MS pressure	17.72	3.88×10^{10}	903.53	1,35,53,045	Nil	Immediate
B	**Thermal Insulation**						
	Thermal Insulation of Damaged Area	NA	$.475\times10^{10}$	133.969	20,09,547	1000000	5.97
			12.115×10^{10}	2854.81	4,28,30,028	10,00,000	5.97

TABLE 2.
BOILER EFFICIENCY CALCULATION

	Loss In KJ/Kg	**%**
Wet Stack Loss	868.64	6.1
Dry Stack Loss	729.55	5.13
Moisture in combustion Air Loss	61.44	0.40
Sensible Heat of Water Vapor	63.9	0.43
Un-burnt Gas Loss	0.00	0.00
Radiation and Unaccountable Loss	251.68	1.58
Total (%) Loss		13.64
Boiler Efficiency		83.50

TABLE 3.
RESULT OF AUDIT IN BOILER

S. No.	Results	Conclusions
1	Wet stack loss (6.10%) and dry stack loss (5.13%) are occurred due to moisture in coal	The moisture of coal should be reduced before use. The moisture can be removed by primary air. The dry coal increases the boiler efficiency
2	6% of radiation losses are increased in the furnace	The radiation loss occurs due to poor insulation. So, insulation should be good in quality e.g. Rock wool insulation
3	Un-burnt carbon in bottom ash and in fly ash was 4.05% and 1.38% respectively	There should be proper crushing of coal. The classifiers in mills should be cleaned and checked periodically

III. RESULTS AND DISCUSSION

Operation data from Gas Turbine can be taken from DCIS monitor. Must be noted, the plants must be steady for duration about two hours and within interval 30 minutes during measurement based on Performance Manual Book. Then, the average data will be shown as table below:

TABLE 3.
GAS TURBINE OPERATION DATA

Gross Power Output	:	95.752 kW
Pemakaian Sendiri	:	440 kW
Net Power Output	:	95.312 kW
Gas Fuel Flow	:	28,954.75 Nm^3/hr
Gas Heating Value	:	1.1118 MMBtu/MMSCF

From the data above, the amount GT's input energy is:

$$\text{Energy in} = Q_{in} = \dot{m} \text{ x LHV } (kCal)$$

$$Q_{in} = 28{,}954.75 \text{ N}m^3/hr\ x\ 1.1118 \text{ MMBtu/}$$
$$\text{MMSCF } x\ 0.00353146\ x\ 252000$$

$$Q_{in} = 286{,}479{,}087.89 \text{ (kCal)}$$

Then, *heat rate* (*net heat rate*) GT1.1 can be obtained:

$$HR_{GT} = \frac{\text{Energy in}}{Energy\ Out}$$

$$HR_{GT} = \frac{28{,}954.75 \frac{m^3}{hr}\ x\ 1.1118 \frac{\text{MMBtu}}{\text{MMSCF}}}{95.3120 \text{ MW}}$$
$$x\ 0.00353146\ x\ 252000$$

$$HR_{GT} = 3{,}005.69\ kCal/kWh$$

So the GT's efficiency will be :

$$\eta_{GT} = \frac{Energy\ out}{Energy\ in}$$

$$\frac{1}{HR_{GT}} = \frac{860 * 100}{3005.6980\ kCal/kWh} = 28.61\ \%$$

HRSG as function of GT exhaust so it can be calculated the energy in of HRSG and taken the data from DCIS monitor as below:

TABLE 4.
HRSG OPERATION DATA

Stage of Steam	unit
HP *Steam Flow* ($\dot{m}_{HP}$)	151.91 Ton/hr
HP *Steam Pressure* (P_{HP})	76.35 Bar
HP *Steam Temperature* (T_{HP})	521.08 °C
LP *Steam Flow* ($\dot{m}_{LP}$)	48 Ton/hr
LP *Steam Pressure* (P_{LP})	5.92 Bar
LP *Steam Temperature* (T_{LP})	325.69 °C
Water	**unit**
Feedwater Flow ($\dot{m}_{fw}$)	199.91 Ton/hr
Feedwater Pressure (P_{fw})	25.08 Bar
Feedwater Temperature (T_{fw})	45.62 °C

Before calculate the amount HRSG's input energy, it must be know how much flow rate that released from GT exhaust. Firstly, determine the combustion reaction based on fuel composition in stoichiometric reaction. The amount of ratio of air will become :

$$AFR = \overline{AF} * \frac{WM\ air}{WM\ fuel}$$

$$= \left\{10.5348 \frac{kg\ mol\ air}{kg\ mol\ fuel}\right\} * \frac{28.97 \frac{kg\ air}{kg\ mol\ air}}{18.177 \frac{kg\ fuel}{kg\ mol\ fuel}}$$

$$= 16.8 \frac{kg\ air}{kg\ fuel}$$

Finally, the total amount mass flow rate of flue gas which is consist of flue gas compound and matched also with CEMS data and it can be obtained the number of mass flow rate of flue gas is 427,68 kg/s. Thus, the number of enegy input of HRSG can be calculate:

$$Q_{in} = \dot{m}_{fg}\ x\ Cp_{fg}\ x\ \Delta T$$
$$= 427.68 \text{ kg/s x } 1.10 \text{ kJ/kg.K } x\ 560.73 \text{ K}$$
$$= 206{,}993{,}312.27 \text{ kCal/hr}$$

Then, it can be calculated how much energy output of HRSG for every stage of pressure.

TABLE 5.
SUMARY OF CALCULATION HRSG'S ENERGY OUTPUT

Component	In		Out		Entalphy kJ/kgK		Flow of Steam		Q
	P gauge (bar)	T (°C)	P gauge (bar)	T (°C)	In	Out	ton/hr	kg/s	kW
HP SH2	76.35	470.09	76.35	521.08	3327	3453	151.91	42.20	5,316.85
HP SH1	78.69	294.8	78.69	470.09	2758	3324	151.03	41.95	23,745.27
HP Evap	78.69	293.38	78.69	294.8	1307	2758	151.03	41.95	60,873.48
LP SH	5.92	164.6	5.92	325.69	2763	3113	48	13.33	4,666.67
HP Eco	117.09	154.74	78.69	293.38	659.6	1307	151.03	41.95	27,160.23
LP Evap	5.92	154.74	5.92	164.6	652.8	2763	48	13.33	28,136.00
LP Eco	25.08	45.62	25.08	154.74	193.3	653.9	199.91	55.53	25,577.37

Therefore, HRSG's efficiency is :

$$\eta_{HRSG} = \frac{Energy\ out}{Energy\ in} = \frac{175.475{,}9\ kW}{240.572{,}23kW} = 72.94\%$$

STG as function of total production of HRSG's steam and it can be taken the data from DCIS monitor as below :

TABLE 6.
STEAM TURBINE OPERATION DATA

Stage of Steam	unit
HP *Steam Flow* ($\dot{m}_{HP}$)	151,91 Ton/hr
HP *Steam Pressure* (P_{HP})	76.35 Bar
HP *Steam Temperature* (T_{HP})	521.08 °C
LP *Steam Flow* ($\dot{m}_{LP}$)	48 Ton/hr
LP *Steam Pressure* (P_{LP})	5.92 Bar
LP *Steam Temperature* (T_{LP})	325.69 °C
Water	**unit**
Feedwater Flow ($\dot{m}_{fw}$)	199.91 Ton/hr
Feedwater Pressure (P_{fw})	25.08 Bar
Feedwater Temperature (T_{fw})	45.62 °C

Next step is calculating the performance of STG. Before that, it must be calculated first for the number of steam product for each HRSG:

$$Q_{HPh}+Q_{LPh}=386{,}016{,}304.8\ \text{kCal/hr} + 98{,}083{,}315.85\ \text{kCal/hr} = 481{,}101{,}187.87\ \text{kCal/hr}$$

So the STG's efficiency is:

$$\eta_{STG} = \frac{153.650\ MW\ x\ 59{,}845.24\frac{kCal}{hr}.MW}{\text{Energi out HRSG}(1.1+1.2+1.3)} = \frac{132{,}115{,}221.13\ kCal/hr}{481{,}099{,}620.36\ kCal/hr} = 27.46\%$$

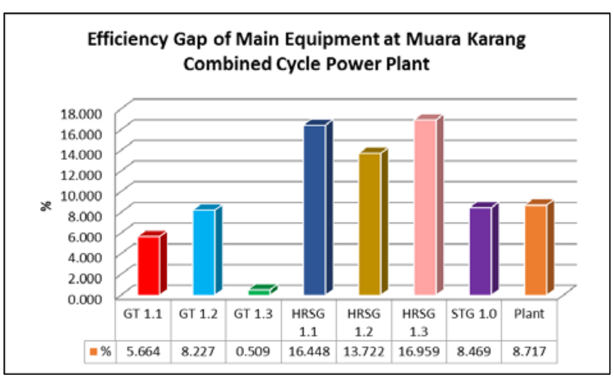

Figure 3. Performance Gap Analysis of CCPP Muara Karang

By using the same calculation, the performance for other unit 1.2 and 1.3 can be obtained. Then, the data compared to commissioning data as in 1995 so it can be obtained the performance gap analysis. Next step is determine how energy flow or energy pattern on Muara Karang Combined Cycle power plant. The energy pattern can be used to analyze more details about the losses on equipment.

Figure 2 shown that HRSG is the main equipment that wasting a lot of energy and has a less efficiency is about 13-16% and followed by Steam Turbine 8%, and also Gas Turbine about 0,5%-8%. Figure 3 shown that bigger losses occurred in HRSG that caused by dry flue gas, the number of its losses vary about 15-17%. This losses can be analyzed more details using data acquisition from site visite using visual inspection to see how the condition of tubing for each pressure is. There are several recommendation for improving HRSG's efficiency and calculated how much of potential saving that will be received for each recommendations. Based on ratio of potential energy, it can be suggested as priority for implementing the recommendations.

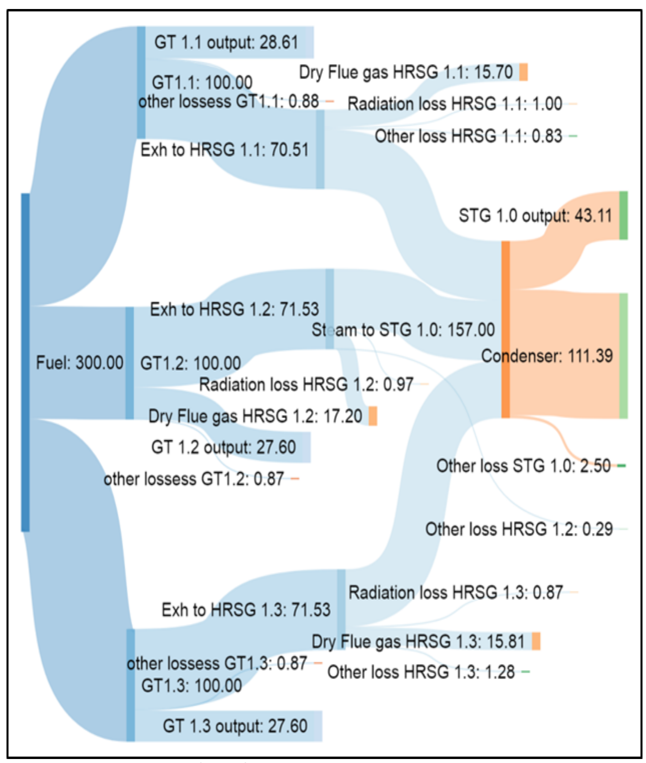

Figure 4. Energy Profile of CCPP Muara Karang using Sankey Diagram

TABLE 7.
STEAM TURBINE OPERATION DATA

No	Energy Saving Recommendation	Potensial Energi Saving (kW)	Potensial Cost Saving (US$)	Payback period (day)	Ratio of potential energy (%)
1	Tube Cleaning using chemical cleaning	936.93	586,249.44	12.06	0.39 %
2	Retubing to replace the damaged fin tube	6,441.64	4,030,627.21	95.70	2.68 %
3	Repair and reposition on buffle plate	187.39	117,249.89	8.77	0.08 %

IV. CONCLUSION

Overall performance at Muara Karang Combined Cycle Power Plant has less efficiency (about 2-3%) than commissioning data and the biggest gap performance occurred in all HRSG (about 13-16%). In the HRSG, it is known that biggest losses caused by dry flue gas (about 68-70%) from sankey diagram. This losses is due to ineffective heat transfer between steam and feed water in tube. In addition, in several area of HP stage found the damaged fin tube and corrosion at tube that leads to header and also many buffle plate is not seated in their proper position. This is also confirmed by the data that taken from site visit. Table 7 shown a list of opportunities for improving the efficiency based on ratio of potential energy as early information for management to minimize loss of efficiency at powerplant. There are several important inputs for the implementation of the next audit such as provide complete data of CEMS with time of survey and GT load also at the time.

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