Application of energy management system in auxiliary power consumption at combined cycle power plant

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Abstract. Reliability and efficiency are a power-plant's commitment to the government in anticipating and overcoming the threat of energy crisis and the environmental impact of energy consumption. The demand for a highly-efficient operation has sparked competitions among power generation industries. The Energy Management System was adopted to evaluate the energy consumption for powering-up electrical equipment in a power plant operation. It is also defined as in-house usage. This study was conducted to analyse Energy Management System compatibility in combined-cycle power plants, utilising Pareto Diagram to discover the most significant consumption of electrical equipment, resulting in the likelihoods of energy and cost savings. This study proposed a mathematical opportunity of saving 342 MWh energy and boosting revenue by 410 million Rupiahs or 28 thousand US Dollars in one year.

1. Introduction

Muara Karang combined-cycle power plant is consists of two gas turbines (GT), two heat recovery steam generators (HRSG), and three steam turbines (ST) with potential power output 710 Megawatts and connected to 150 kV electrical distribution grid. In 2020, there was a decline in the plant load profile due to the integration among coal-fired power plants, which guarantees lower electricity production costs. The role of IPP has a positive and negative effect. The positive impact is increased competition between companies to carry out operational activities that are effective, efficient, and eco-friendly [1,2]. The negative effect is load profile reduction due to economic dispatch. Plant operations in partial load mode cause inefficiencies of power plants.

Energy Management System (EMS) is adopted to improve plant efficiency, following the international standard ISO 50001[3]. EMS benefits are increased revenue, reduce production costs, and reduce environmental impacts [4] [5]. The EMS targets in power plants divided into four types, such as the efficiency of generation equipment (GT, HRSG, and ST), heat rate values, specific fuel consumption (SFC), and auxiliary power consumption [6].

This study focuses on auxiliary power consumption in the power plant auxiliary system. Auxiliary power consumption was chosen because the EMS can be implemented by managing the operating time of electrical equipment. EMS application provides a reduction in service power consumption, commonly called in-house usage, as a part of the production cost [7]. Based on this account, this study aims to define the technical and economic feasibility of implementing EMS in a power plant auxiliary system. The technical feasibility is the efficacy of EMS against reducing in-house usage without degrading the
reliability of the power plant. The economic viability includes the benefits achieved after implementing EMS in the power generation system.

2. Methodology

The energy audit is an approach to find out the strengths and weaknesses of energy performances in many kinds of industries [8]. The method used in conducting an energy audit is the Pareto chart. Energy and cost savings are later assessed as an outcome of evaluation system or audit [9]. The audit consists of three stages: preliminary energy audit, development of improvement, and evaluation [10]. Two steps perform the data collection technique. The first is recording the energy consumption of the auxiliary transformer measuring unit and measuring the current of each equipment on the breaker. The second is collecting the necessary plant operation data from the distribution control system (DCS).

2.1. Pareto chart

Pareto chart is a tool to determine the most significant energy users in a graph by grouping equipment objects. The result shows a distribution energy user equipment from largest to smallest energy user.

2.2. Energy-saving

Energy-savings can be achieved by implementing the outcome of an energy audit. It can be calculated using a formula of actual energy consumption minus old energy consumption or described as:

\[ ES \text{(kWh)} = EC_{\text{Actual}} \text{(kWh)} - EC_{\text{Old}} \text{(kWh)} \]  

(1)

2.3. Cost-saving

Cost savings are usually associated with energy savings. Cost-saving can be calculated using the energy-saving formula multiplied by the price of electricity production or described as:

\[ CS \text{(IDR)} = ES \text{(kWh)} \times ep \text{(IDR/kWh)} \]  

(2)

2.4. Preliminary energy audit

The first stage of energy audit begins with an analysis of the existing situation to determine the total energy consumption of electricity production. Energy consumption data for each electrical equipment is recorded at a 100% load. Electrical equipment data in power plants are grouped into ten, based on function and area. Load distribution is described in Figure 1.

![Figure 1. Pareto chart power consumption.](image)

Based on Figure 1, it is acknowledged that total power consumption is 8.5 MW. The steam turbine common group is the largest energy-consuming group with a value of 6.28 MW or 73.8% of all in-house usage. The second largest group is the gas turbine and water intake groups, with an amount of 0.4 MW or 4.7% of the entire in-house usage. The rest are non-substantial groups.
2.5. Development of improvement

Development improvement is the second step of the energy audit to explore energy-saving opportunities. Energy-savings can be considered successful if the implementation does not degrade plant reliability or augment the risk. Energy-saving opportunities classified from most significant to the smallest group of energy users. The most significant energy consumption in a power plant is fan and pump equipment because they have to operate continuously [11]. Energy saving in fan equipment is obtained by managing operation time. When the plant’s load is low, the fans can be shut down [12].

The electrical equipment in ST common group has an important task. Thus, it is not necessary to manage the operating time. The second-largest energy-consuming group is the GT group. Consists of GT auxiliary and HRSG auxiliary electrical equipment. This study focused on and use data operations of GTG 2.1 as an audit target. The distribution of electrical equipment is described in Table 1.

Table 1. Power consumption gas turbine group equipment in December 2019.

| No | Description             | kW   | %   | No | Description             | kW   | %   |
|----|-------------------------|------|-----|----|-------------------------|------|-----|
| 1  | CCW pump A              | 141.75 | 34.83 | 12 | Blowdown pump A        | 14.67 | 3.60 |
| 2  | Main lube oil A         | 53.73  | 13.20 | 13 | Control oil A          | 8.97  | 2.20 |
| 3  | CCW Fan A               | 15.95  | 3.92  | 14 | Enclosure fan A        | 7.47  | 1.84 |
| 4  | CCW Fan B               | 15.90  | 3.91  | 15 | Enclosure fan B        | 7.76  | 1.91 |
| 5  | CCW Fan C               | 16.69  | 4.10  | 16 | Turbine Cooling Air A  | 5.97  | 1.47 |
| 6  | CCW Fan D               | 16.06  | 3.95  | 17 | Turbine Cooling Air B  | 5.92  | 1.45 |
| 7  | CCW Fan E               | 15.69  | 3.86  | 18 | Seal oil A            | 5.30  | 1.30 |
| 8  | CCW Fan F               | 15.95  | 3.92  | 19 | Turbine Cooling Air C  | 4.91  | 1.21 |
| 9  | CCW Fan G               | 16.32  | 4.01  | 20 | Lube Oil Mist Eliminator Pump A | 4.00 | 0.98 |
| 10 | CCW Fan H               | 16.48  | 4.05  | 21 | Seal oil vacuum pump  | 1.25  | 0.31 |
| 11 | CCW Fan common A        | 15.95  | 3.92  | 22 | Vapor extractor       | 0.24  | 0.06 |

Based on empirical approaches, the first saving opportunity is a closed cooling water fan (CCW). It is part of the CCW GT system, which operates as a cooling system for gas turbine, generator, and auxiliary equipment. The heat in CCW was cooled by the CCW heat exchanger (HE) and CCW fan. CCW fan consists of 9 fans for each GT. Another saving opportunity is a blowdown pump device. A blowdown pump is part of the blowdown system, which operates as a shelter of overflow water in the HRSG drum. Two pumps work in a redundant system, and the impeller type is centrifugal.

2.6. Performance evaluation

This section outlines a comprehensive evaluation of energy-saving opportunities, as described earlier. A depth assessment of each equipment uses empirical studies based on historical data and plant’s manual books to strengthen the hypothesis that electrical equipment can be adjusted in a working scheme.

2.6.1. CCW fan GT

Typically, the nine fans are running for each GT with one fan in standby. The controlled parameter is CCW outlet temperature. The CCW outlet temperature should be kept below 35 °C by operating the standby fan manually to help the cooling. If the CCW outlet temperature is rising rapidly until reach 42 °C, then water will be discharge and filled with fresh water from CCW tank. It should be noted that the operation of the CCW system also depends on GT load and ambient temperature.

In this paper, there are three conditions of fan operating time. First, no standby fan when GT at maximum load, over 220 MW or ambient air temperature more than 30 °C. Second, one standby fan when GT at partial load or ambient temperature around 28.5 °C. Third, two standby fans when GT at minimum load around 120 MW or ambient air temperature below 26 °C.

2.6.2. HRSG blowdown pump

Regularly, the blowdown pump works automatically with temperature and level of the water as controlled parameters. The water temperature should be kept below 60 °C and level approximately -400
to 200 mm. If the water level is higher than 200 mm, the level control valve will be open to discharge water toward the wastewater pond. Then, Water level rise is slow due to HRSG efficiency. Slow water build-up keeps the temperature in a tank under control due to the natural cooling process. If EMS is applied, the tank water will be discharged to the pond by manually operating the level control valve.

3. Results and discussion

3.1. CCW fan GT
The pilot study in the CCW fan system was carried out using three conditions based on section performance evaluation. In a one-day test in January 2020, the first condition occurs for 7 hours (10 pm to 4 am), the second condition occurs for 4 hours (8 to 10 pm and 4 to 6 am), and the third condition occurs for 13 hours (1 to 8 pm and 6 to 12 am). DCS data showed that the CCW outlet temperature remains under control below 35 °C across a daily load profile and ambient air temperature. There was no performance degradation in the CCW fan system before and after implementation of the EMS program.

The CCW fan operating time in Figure 3 is used to determine the effect EMS program. Total savings of one gas turbine is 114.24 kWh per day or 228.48 kWh per day for two gas turbines. Table 2 shows the results of the EMS program at CCW GT. Operational parameter before the EMS program used data in 4th March 2011. The operational parameter after the EMS program used data in 31st December 2019.

![Figure 2. CCW fan system performance before EMS.](image1)

![Figure 3. CCW fan system performance after EMS.](image2)

The CCW fan operating time in Figure 3 is used to determine the effect EMS program. Total savings of one gas turbine is 114.24 kWh per day or 228.48 kWh per day for two gas turbines. Table 2 shows the results of the EMS program at CCW GT. Operational parameter before the EMS program used data in 4th March 2011. The operational parameter after the EMS program used data in 31st December 2019.
Table 2. Comparison of CCW fan operations GT 2.1.

| No. | CCW fan GT     | Power (kW) | Before EMS/day (kWh) | After EMS/day (kWh) |
|-----|----------------|------------|----------------------|---------------------|
|     |                |            | 13 Hours | 24 Hours | 7 Hours | 4 Hours | 13 Hours |
| 1   | Fan common A   | 15.95      | 0        | 382.80   | 111.65  | 63.80   | 207.35   |
| 2   | Fan A          | 15.95      | 0        | 382.80   | 111.65  | 63.80   | 207.35   |
| 3   | Fan B          | 15.90      | 0        | 381.60   | 111.30  | 63.60   | 206.70   |
| 4   | Fan C          | 16.69      | 0        | 400.56   | 116.83  | 66.76   | 216.97   |
| 5   | Fan D          | 16.06      | 0        | 385.44   | 112.42  | 64.24   | 208.78   |
| 6   | Fan E          | 15.69      | 0        | 376.56   | 109.83  | 62.76   | 203.97   |
| 7   | Fan F          | 15.95      | 0        | 382.80   | 111.65  | 63.80   | 207.35   |
| 8   | Fan G          | 16.32      | 0        | 391.68   | 112.42  | 64.76   | 212.16   |
| 9   | Fan H          | 16.48      | 214.24   | 0        | 0       | 0       | 214.24   |
|     | Total          | 129.04     | 214.24   | 2,701.44 | 673.68  | 450.24  | 1,677.52 |

Total energy (kWh) | 2,915.68 | 2,801.44 |
Energy saving (kWh) | 114.24    |

3.2. HRSG blowdown pump

Blowdown pump test results explain that blowdown pump and blowdown HE functions can be deactivated. Succeed parameter test indicated by the absence of a water temperature increment in the blowdown tank and the water level rise is slow as described in Figure 4 and Figure 5. In Figure 5, the blowdown control valve will be manually open when the water level is rise until reach 200 mm, Operational parameter before the EMS program used data on 4th March 2011. The operational parameter after the EMS program used data on 31st December 2019.

![Blowdown tank outlet drain temperature.](image_url)

**Figure 4.** Blowdown tank outlet drain temperature.

![Blowdown tank level.](image_url)

**Figure 5.** Blowdown tank level.

The side effects of this activity are a motor failure if it was not running for a long time, so specialized treatment was needed to avoid motor damage. The EMS result is 351.96 kWh per day or 703.92 for two gas turbines. The EMS results in blowdown pump presented in Table 3.

Table 3. Comparison of blowdown pump operation.

| No   | Blowdown pump | Power (kW) | Before EMS/day (kWh) | After EMS/day (kWh) |
|------|---------------|------------|----------------------|---------------------|
| 1    | HRSG 1 pump A | 14.67      | 351.96               | 0                   |
| Total|               | 14.67      | 351.96               | 0                   |

Energy saving (kWh) 351.96
3.3. EMS benefits

The EMS program calculation is carried out by the amount of energy-saving data from Table 3 and Table 4. The EMS benefits is described in Table 4. There is some limitation used in EMS program, such as energy price is 8.2 cents per kWh and daily plant operational data in 31st December 2019.

**Table 4. EMS benefits per GT.**

| No | Description    | Day | Energy-saving (kWh) | Month | Year  | Day | Month | Year  |
|----|----------------|-----|---------------------|-------|-------|-----|-------|-------|
| 1  | Blowdown pump  | 351.96 | 10,558.80         | 128,465.44 | 29.13 | 873.83 | 10,631.62 |
| 2  | CCW fan        | 114.24 | 3,427.20           | 41,697.60   | 9.45   | 283.63 | 3,450.84  |
|    | Total          |       | 466.20             | 13,986.00  | 170,163.04 | 38.58 | 1,157.46 | 14,082.46 |

*Assumption 1 USD = IDR 14500

The total power consumption for plant operation is 8,500 kW. For a year, energy consumption for generated electricity is 74,460,000 kWh. Then, total energy saving in a year at 340,326.08 kWh. If the EMS program applied for a year, there would be a decrease in energy consumption for 0.46%.

4. Conclusion

In this paper, the EMS program can be implemented in a power plant auxiliary system by managing the operation time of electrical equipment such as the CCW fan system and HRSG blowdown pump. The new operating time did not degrading plant reliability or augment the risk. Technical feasibility of equipment when implementing EMS—concluded that energy-savings could reduce auxiliary power consumption in a combined cycle power plant. Total energy-saving calculated in 340 MWh, and growing revenue from cost savings is 28 thousand US Dollars in one year of operating power plants.

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