Gas Turbine Hidden Capacity Recovery by Inlet Air Filter Variation Method to Produce Clean and Efficient Energy

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Abstract. In the F-series gas turbine with the capacity of 250MW, as time goes by, the power produced will drop below its initial capacity, this refers as a hidden capacity. Hidden capacity occurs due to several causes, one of them is the decreased of compressor efficiency. This happens because the Inlet Air Filter (IAF) is unable to filter particles more than 10 µm, as a result particles infiltrate compressor which can prompt scaling on compressor blade. This paper will discuss an effort to recover the hidden capacity by varying air filtration system in the IAF. The variation of IAF use High Efficiency Particulate Air (HEPA) filter and combination of pre-filters, consist of bag filter and coalescer, which can filtrate particles less than 10 µm and 1 µm. By implement this modification, compressor efficiency remains at 90.1%, compared to existing IAF, compressor efficiency drop to 85% and continuously. Because the compressor efficiency is maintained, power plant efficiency can also be maintained to avoid heat rate drop by 40 kCal/kWh. As a summary, after modifying the IAF, the F-Series Gas Turbine can produce more reliable power capacity, thus, the gas turbine can produce maximum load efficiently and hidden capacity can be recovered.

1. Introduction

The power plant capacity is increasing as the needs of electricity increase in Indonesia. Due to an increased electricity consumption, power plants should be able to produce electricity efficiently and reliable. It is intended that the energy needed to produce electricity can be used properly. Therefore, the power capacity of power plant can be as same as its initial capacity.

In the actual performance, the power produced by power plants can be decreased and different from its initial power capacity, thus, there will be hidden capacity in electricity production. In F-series Gas Turbine, the hidden capacity happens. The actual power produced by F-series gas turbine with capacity of 250MW is not in line with its design and the decrease happens moreover. The hidden power capacity happens because of the decreased in power plant performance, specifically the efficiency of compressor gas turbine that operates countinuously.

Figure 1 shows the increase of outlet temperature in compressor F-series gas turbine. According to the latest research by Okwaldu [1] [2], the increase of outlet temperature in compressor F-series gas turbine can happened rapidly, consequently, the compressor efficiency drop can not be avoided. The decrease of compressor efficiency leads to power produced reduce, thus, hidden capacity occurs. The compressor efficiency decreased happens because scaling, fouling, and erosion occurs on compressor’s blade because of air impurities and poor air filtration [3] [4]. Blade damage will resulting a decrease in pressure of the compressor [5]. The compressor’s blade scaling arise because
particles with the size of $< 10\mu m$ infiltrate in to the compressor. This occurrence happens because air filtration system in Inlet Air Filter (IAF) gas turbine is deficient.

![Compressor outlet temperature trendline of existing F-series gas turbine](image)

**Figure 1.** Compressor outlet temperature trendline of existing F-series gas turbine

Existing filters in Gas Turbine F-series has filtration capability with particle’s size $> 10\mu m$. Air filter with a capability to filtrate particle with the size of $< 10\mu m$ could be used and this type of filter is called High Efficiency Particulate Air (HEPA) Filter. The filter modification in gas turbine Inlet Air Filter might be the one solution needed. In this paper, the modification of filter using High Efficiency Particulate Air Filter in IAF Gas Turbine F-Series to prevent hidden capacity is thoroughly explained.

2. Literature Review

2.1. High Efficiency Particulate Air Filter

F-series gas turbine uses air filter to filtrate air from particles. To filter more and smaller particles, High Efficiency Particulate Air (HEPA) filter can be used. HEPA filter has particle filtration standard 99,95% [6] or 99,7% [7] particles with 0,3 $\mu m$ size. The smaller particles that filtered out, the probability of scaling on compressor blade becomes lesser.

Table 1 shows the specification of HEPA filter. To optimize the use of HEPA filter in power plants, it can be combined with another filter to filtrate the bigger particles.

| Name                     | HEPA Filter                  |
|--------------------------|------------------------------|
| Function for             | $< 1\mu m$                   |
| EN Class                 | E11                          |
| Efficiency (@0.3$\mu m$) | 99.95%                       |
| Rated Air Flow           | 43                           |
| Total Pressure Drop (Pa) | 1500                         |
| Estimated Filter Life    | 18000                        |

2.2. Governing equation in gas turbine

The equations that used in this paper are the work of compressor, gas turbine, heat rate, and compressor efficiency, as follows [8][9]:

a) Compressor’s Work
\[ W_C = \frac{C_{Pa} x T_1 \left( \frac{P_2}{P_1} \right)^{\frac{T_0 - 1}{T}}}{\eta_C} \]  

(1)

b) Gas Turbine

\[ W_T = m_g \cdot C_{Pg} \cdot (T_3 - T_4) \]  

(2)

c) Heat Rate Calculation

\[ Heat \ rate = \frac{HHV \times m_{fuel}}{P_{Out} \times 1000} \]  

(3)

d) Compressor Efficiency

\[ \eta_C = \frac{T_1}{T_2 - T_1} \left( \frac{P_2 + P_1}{P_1} \right)^{\frac{k-1}{k}} - 1 \]  

(4)

\[ T \] = Temperature (K)

\[ W_T \] = Gas turbine power output (MW)

\[ \dot{m} \] = Mass flow rate (kg/s)

\[ P_{Out} \] = Power Output (MW)

\[ C_P \] = Specific heat capacity in constant volume (kJ/kgK)

\[ h \] = Rate of enthalpy (kJ/kg)

3. Inlet Air Filter Variation Method

The existing filtration system of F-series gas turbine is using conventional filters that can filtrate particle with the size of > 10 \( \mu \text{m} \). Thus, the particles with the size less than 10\( \mu \text{m} \) get through into compressor that provoke scaling on compressor blade. The scale on compressor’s blade can initiate the compressor efficiency to decrease. Hence, the declined of power capacity occurs more often and the hidden capacity becomes bigger. Therefore, the modification of air filtration system is needed to recover hidden capacity.

A brief review of existing air filtration system problem in Gas Turbine F-series with its solution are describe in table 2.

| No. | Design Review | Design Improvement |
|-----|---------------|--------------------|
| 1   | Existing filtration system > 10\( \mu \text{m} \). | Filter with filtraion capability of < 10\( \mu \text{m} \) need to be used. |
| 2   | Unprotected main filter so that differential pressure can arise quickly. | Use pre-filters as a protection. |
| 3   | The pre-filters will get dirty quickly and need to do a replacement. | Use pre-filters that have rewashable characteristic. |
| 4   | No differential pressure indicator is installed. | Add differential pressure indicator at each filtration level. |

3.1. Design study of gas turbine air filtration system modification

There are several steps of research before implement the modification of air filter in Inlet Air Filter Gas Turbine F-series, as follows:
3.1.1. Air quality measurement

![Pollutant Distribution in Muara Karang](image)

**Figure 2.** Pollutant distribution in Muara Karang

The effect of environmental condition for inlet air filter gas turbine was studied that could be the basis for filter selection [10]. The sample of air in Muara Karang, North Jakarta is measured to find out the pollutant distribution as shown in figure 2. Pollutant which size less than 10µm are quite dominating.

3.1.2. Type of air filters

By understanding the distribution of pollutant, a suitable type of filter can be chosen to recover hidden capacity. Filters which can filtrate particle less than 10µm are needed to be able to filtrate air from more than 55% pollutant. As shown in table 3, High Efficiency Particulate Air Filter is chosen as the requirements are enough.

| Grade  | Size   | ASH filter class | EN filter class | Particles separated                                      | Filter        |
|--------|--------|------------------|-----------------|---------------------------------------------------------|---------------|
| Coarse | > 10 µm| 7 G4             | -               | Pollen, fog, spray                                       | Coalescer     |
| Fine   | > 1 µm | 10 F5            | -               | Spore, cement, dust, dust sedimentation                  | Bag filter    |
| EPA and HEPA | > 0.01 µm | 16 E11 | -               | Metal oxide smoke, carbon black, smog, mist, furnes | HEPA filter   |
3.1.3. Filter configuration

The existing filter configuration, in figure 3, which using conventional filter has cheap installation cost and long operating period but has a filtration capability >10 µm, thereby the compressor’s efficiency is decreased rapidly. Filter’s scheme that only using HEPA filter, as shown in figure 4, has a cheap installation cost and a low difference pressure at the early period. Nonetheless, the main filter will get dirty quickly and filter replacement should be done necessary in a short period. The pre-filters, as shown in figure 5, are added to handle this issue. Pre-filter consist of coalester that can filter out particles bigger than 10µm and bag filter for particles between 1µm and 10µm. Thus, HEPA as the main filters will not get dirty immediately and only bear 25% of filtration process. The differential pressure’s indicators are installed to monitor filter’s performance. Approximately, 3 billion rupiah of investment is needed for this implementation. However, this will be cheaper than replacing every filter when it becomes dirty.
3.2. Filter pressure difference modeling

Figure 6 shows pressure difference simulation using conventional existing filters and figure 7 using only HEPA filter. Pressure difference in these two configurations are low in the early time. However, as shown in figure 6 with conventional filter, particles smaller than 10 µm are infiltrate and resulting hidden capacity. Whereas, in figure 7, by using only HEPA filter, particles bigger than 1 µm will stick to it excessively causing filters dirty in a short period, hence, a filter replacement will cost additional expense.

As shown in figure 8 above, HEPA filter is protected with pre-filter, videlicet, coalescer and bag filter. Differential pressure will be higher continuously because of the soiled pre-filter (coalescer). Coalescers are using non-cartridge cellulose material that have rewashable and reusable characteristics.

4. Implementation Results And Analysis

The implementation results is carried out by comparing the F-series gas turbine, that still uses conventional filters, with the F-series gas turbine that has been implemented a modification of air filtration system in IAF using HEPA filter to avoid hidden capacity. The analysis consist of Compressor Pressure Discharge (CPD), Operating Netto Power Capability, Net Plant Heat Rate (NPHR), Inlet Air Filter Differential Pressure, and Compressor Efficiency.
4.1. Compressor pressure discharge

Figure 9 above shows comparison of Compressor Pressure Discharge (CPD) F-series Gas turbine that using conventional filter with the implemented filter modification. The black squares represent CPD gas turbine that uses conventional filter, while the red circles represent CPD gas turbine that uses air filter modification, and the blue triangles represent difference between those two values. Gas turbine that has used HEPA filter and pre-filter has a more constant CPD compared to those that still use conventional filters. CPD are higher in gas turbine that uses conventional filters during initial operation. However, after 11 weeks of operation, it has dropped lower than gas turbine that uses modification filters. Therefore, gas turbine that uses modification filters has better reliability so that hidden capacity can be avoided.

4.2. Net operating power capability

Net Power Capability in HEPA filter gas turbine can be maintained better than conventional filter gas turbine, as shown on figure 10 below. Net Power Capability of existing air filtration system continuously drop. It can be happened because particles are filtered considerably, as a consequence, those barely invade to compressor’s blade and need to be restored by performing bladewashing. In the modified air filtration system, it may drop but stagnant and still higher than the existing after performing bladewashing. Hence, the compressor performance is stable. Deviation of power netto capability shows hidden capacity recovered.
4.3. Net Plant Heat Rate

Net Plant Heat Rate (NPHR) between F-series Gas Turbine that using existing and modified air filtration system are shown in figure 11. NPHR of the existing air filter is continuously increase and at the 38 weeks of operation, it needs offline bladewashing to restored. Power plant unit must stop to do this action, so there will be power loss due to inactive gas turbine.

Otherwise, by using HEPA filter, the decrease of power plant efficiency can be avoided, NPHR may increase but stagnant as shown on figure above, so it does not need to perform offline bladewashing and power plant can produce electricity continuously. Figure 11 shows total Net Plant Heat Rate that can be avoided are 40kCal/kWh.

4.4. Inlet Air Filter differential pressure

Figure 12 below shows IAF difference pressure of F-series gas turbine that uses conventional filter and air filter modification. The black squares, red circles, green triangles, and blue stars represent respectively IAF difference pressure of conventional filter, HEPA and pre-filters, pre-filters only, and HEPA filter only. It shows IAF difference pressure of F-series gas turbine that using modification of air filter will be higher than conventional filters. Difference pressure in HEPA filter becomes higher constantly, as shown in figure 12, because the DP in pre-filter are also higher. Thus, it proves that pre-
filters (bag filters and coalescers) filtrate dominant particles with the size of $>1\mu m$ and HEPA filters do filtration of $<1\mu m$.

4.5. Compressor Efficiency

Figure 13 shows compressor outlet temperature and compressor efficiency by varying inlet air filter. The black squares represent compressor outlet temperature of gas turbine that uses conventional filter, whereas the green triangles represent that uses air filter modification. The red circles represent compressor efficiency of gas turbine that uses conventional filter, while the blue triangles represent that uses air filter modification. Figure 13 shows compressor outlet temperature of gas turbine F-series that uses conventional filters are getting hot faster than that uses filter modification. As a consequence, the existing gas turbine gets its compressor efficiency decreased. Whereas, gas turbine with air filter modification shows the compressor outlet temperature gets high constantly but insignificant, hence, the compressor efficiency does not affected thoroughly.
As a summary, variation of inlet air filters in F-series gas turbine comparison are shown in table 4 below. Implementation of HEPA filter and pre-filters combination needs approximately 3.8 billion rupiah. The F-series gas turbine and power plant performance are more stable by using these filters combination than the existing one. Because of rewashable pre-filter, the life time and effort to restore to initial condition of this variation are longer and easier to achieve. HEPA filter, as the main filter, is protected by pre-filters so it does not get dirty quickly. The pre-filter can be washed when the unit is online. The NPHR and Compressor Efficiency of modified inlet air filter are more stable than the existing one. In existing conventional filter F-series gas turbine, to restore to its initial condition, offline bladewashing is performed and it needs 7.8 billion rupiah to perform this action.

| No. | Description                  | Existing filter                              | HEPA filter       | HEPA filter and pre-filters |
|-----|------------------------------|----------------------------------------------|-------------------|----------------------------|
| 1.  | Implementation cost          | 1.2 billion rupiah                           | 2.9 billion rupiah| 3.8 billion rupiah         |
| 2.  | Performance                  | Compressor efficiency decreased, need offline bladewashing | Reliable          | Reliable                   |
| 3.  | Life time                    | 12000 EOH                                    | 12000 EOH         | 24000 EOH                  |
| 4.  | Restore to initial condition | Offline bladewashing                         | Replace main filter | Wash pre-filter            |
| 5.  | NPHR                         | Increase rapidly                             | Stable            | Stable                     |
| 6.  | Compressor efficiency        | Decrease rapidly                             | Slowly decrease   | Slowly decrease            |
| 7.  | Potential loss of production | 7.8 billion rupiah to perform offline bladewashing | N/A               | N/A                        |

The implementation analysis of air filter modification using HEPA filter and pre-filters show CPD, compressor efficiency, NPHR, and netto power capability that more reliable than gas turbine that using conventional existing air filters. Netto power capability difference is 10MW in the peak of netto power capability margin from these two units. In the existing air filtration system, offline bladewashing is needed to perform to restore the F-series gas turbine efficiency. Bladewashing does cleaning compressor blade from particle that result scaling on it. More cost is needed to perform this action and gas turbine must in offline mode. The power produced are less due to this action. Besides, after restoration act, the condition of gas turbine not the same as its initial condition. To fully restore the efficiency of gas turbine that using existing filters, overhaul must performed and it will cost more than offline bladewashing. Moreover, overhaul in power plant usually done when power plant has operating time more than one year.

In the modified air filtration system F-series gas turbine, it does not need offline action to restore its condition. HEPA filter, as the main filter, can not get dirty quickly because of pre-filters. The soil pre-filters can be washed when power plant is online. Gas turbine condition is stagnant so it does not need to perform bladewashing. Thus, power plant can produce power more reliable and efficient because there is less power loss than the existing one. Therefore, it shows that hidden capacity in power plant can be recovered by using air filter modification with HEPA filter and pre-filters in Inlet Air Filter gas turbine.

5. Conclusion
In context of this research, an air filter modification of F-series gas turbine using HEPA filter and pre-filters is implemented to recover hidden capacity in power plant. Air filter modification in IAF F-series gas turbine can affect the ability of the power plant unit to operate more stable and the reliability can be maintained because the operating power netto capability and net plant heat rate do not significantly or rapidly change, thus, the power plant unit is more efficient. The combination of HEPA
filter and pre-filters makes the air that get in to the compressor cleaner, so that particles with the size of > 1µm cannot get through to compressor that can cause scaling on the compressor blade. The compressor efficiency can last at a value of 90.1% so that the power plant efficiency can last longer which prevent the hidden capacity to occur. The air filter modification in IAF gas turbine prevents a decrease in heatrate of 40 kCal/kWh. The implementation of air filter modification in F-series gas turbine using HEPA filter and pre-filters can maintain power plant reliability, thus, it can recover the hidden capacity that occurs when using conventional existing filters.

6. References
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