# Energy and Financial Analysis of Dual Fuel Gas Turbine Generator System

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*Abstract -* **The paper focuses on analyzing the energy and financial viability of a dual-fuel gas turbine generator (GTG) system, which operates on both diesel and natural gas. The study evaluates the GTG's performance in a gas processing facility located in East Java, which utilizes three GTGs configured to run two at a time with one on standby, each with a capacity of 13.7 MW. The exhaust gases from these GTGs are currently unused, representing a potential energy resource for the facility's steam requirements. To address this, a Heat Recovery Steam Generator (HRSG) system is proposed to harness the exhaust gas heat, producing medium-pressure (MP) and low-pressure (LP) steam. The study compares the thermal efficiency, power output, and cost-effectiveness of natural gas versus diesel fuel, considering their respective exhaust temperatures and flow rates. Results indicate that natural gas provides higher thermal efficiency, lower fuel consumption, and reduced emissions compared to diesel. Additionally, the HRSG using natural gas can produce more steam, enhancing the facility's overall efficiency. Financially, using natural gas could result in substantial savings, amounting to approximately $3,255.1 per hour. This analysis concludes that natural gas offers a more cost-effective and environmentally friendly solution for GTG operations, optimizing both the steam production and power generation capacity of the facility.**

*Keywords:* Generator, HRSG, Dual Fuel, Diesel, Natural Gas.

## I. INTRODUCTION

Today's energy systems are gradually evolving to adapt energy to meet the increasing challenges of society. Uncontrolled urbanization, changing social structures, new energy markets and competitive conditions have changed the key success factors for electricity generation [1]. In addition, the interest in cleaner, flexible and cheaper energy sources affects both supply and demand side activities, requiring new technologies and decision-making processes to meet the challenges [2].

The environmental impact of energy use has led to attention on sustainable solutions to important problems of our generation such as energy poverty and global warming [3]. Environmental issues have offered new challenges to the energy production sector, starting with the need to improve the efficiency of thermodynamic systems to save fuel consumption [4]. The average temperature of global warming on the Earth's surface has now increased by $0.74 \pm 0.18°C$, this increase is due to the process of increasing the average temperature of the Earth's atmosphere, oceans and land. The emission that most affects air quality is carbon emissions, especially carbon dioxide ($CO_2$) emissions [5]. $CO_2$ gas makes the largest contribution to global warming at 50%. This $CO_2$ gas absorbs and reflects back wave radiation emitted by the earth, so that the heat will be stored on the earth's surface [6].

Developments in the fields of industry, technology and property have been very rapid lately. One of these developments also occurs in turbines. The first design of a gas turbine was made by John Wilkins an Englishman in 1791. The system works with gas from burning coal, wood or oil, the compressor is driven by a turbine by means of a gear chain. In 1872, Dr. F. Stolze designed a gas turbine system that used a double-stage axial compressor driven directly by a double-stage reaction turbine [7].

In 1908, in accordance with H. Holzworth's conception, a gas turbine system was built that tried to use the combustion process at a constant volume. However, it was discontinued due to problems with combustion chamber construction and combustion gas pressure that changed with load. In 1904, the "Societe des Turbomoteurs" in Paris built a gas turbine system whose construction was based on Armengaud and Lemate's design using liquid fuel. The incoming combustion gas temperature was about $450°C$ with a pressure of 45 atm and the compressor was directly driven by the turbine. Subsequently, in 1935 the gas turbine system underwent rapid development where an efficiency of approximately 15% was obtained. The first gas transmitting aircraft was completed by "British Thomson Houston Co" in 1937 according to Frank Whittle's 1930 conception.

**1.1 Gas Turbine Engine**

Gas turbine engine is a device that utilizes gas as a fluid to rotate a turbine with internal combustion. In a gas turbine, kinetic energy is converted into mechanical energy through compressed air that rotates the turbine wheel to produce power. The simplest gas turbine system consists of three components: compressor, combustion chamber and gas turbine. The working principle of the gas turbine system is that air enters the compressor through the airinlet. The compressor functions to suck and increase the air pressure, so that the air temperature also increases. Then this pressurized air enters the combustion chamber. In the combustion chamber, the combustion process is carried out by mixing pressurized air and fuel. The combustion process takes place under constant pressure so that it can be said that the combustion chamber is only to increase the temperature.

The combustion gas is flowed to the gas turbine through a nozzle that serves to direct the flow to the turbine blades. The power generated by the gas turbine is used to rotate its own compressor and rotate other loads such as electric generators and others. After passing through this turbine the gas will be discharged out through the exhaust channel. Figure 1 illustrates one of the existing forms of gas turbines.



**Figure 1: Gas Turbine**

In one of the Gas Processing Facilities companies located in East Java, there are 3 GTGs with dual fuel. Fueled by natural gas and diesel. Which works 3 x 50%. This means that it operates with only 2 GTGs running and 1 GTG in standby position. Each has a capacity of 13.7MW. However, the exhaust gas from this GTG has not been utilized. So one of the efforts to overcome this problem is to design the exhaust gas from the GTG as a steam generator that will be needed in the gas processing facility at the company. The steam demand in this company is around 232 klb/hr for MP steam and 141 klb/hr for LP steam. It is expected that with the heat recovery steam generator (HRSG) process, some of the steam can be covered from the utilization of exhaust heat in this dual fuel GTG.

The main components in a gas turbine as shown in Figure 2 are:

a) Compressor, to enter outside air and then compress the air.
b) Combustor, where fuel (fuel) is added to pressurized air and then burned.
c) Turbine, converting energy from gas with high velocity into rotational power through expansion.
d) Output Shaft and Gearbox, providing rotational power to mobile equipment.
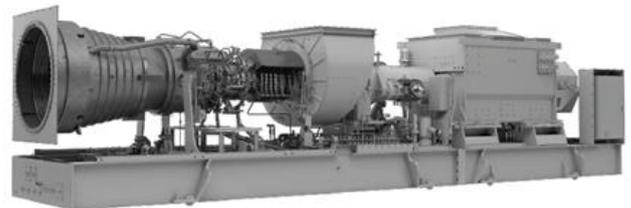e) Exhaust, directing low emission exhaust gases out of the turbine.
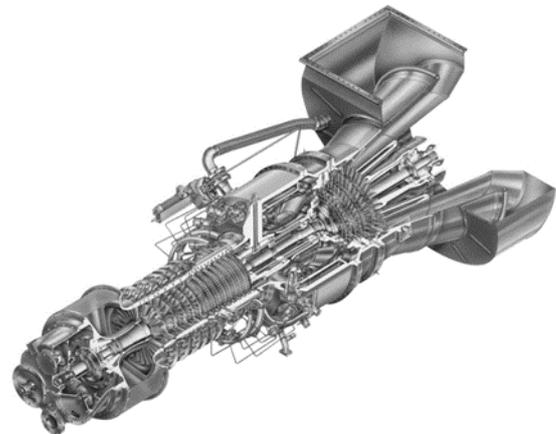


**Figure 2: Gas Turbin Generator**



**Figure 3: Titan 130 Mechanical Drive Package**

The mechanical drive used in this company uses Titan 130 as shown in Figure 3. And the process of utilizing this exhaust gas can use a Heat Exchanger. A heat exchanger is a device where heat transfer occurs from a fluid with a higher temperature to a fluid with a lower temperature. The heat transfer process can be done directly or not. The point is:

a) A direct heat exchanger is where the hot fluid will mix directly with the cold fluid (without any separators) in a particular vessel or room.
b) Indirect heat exchanger is where the hot fluid is not directly related (indirect contact) with the cold fluid. So the heat transfer process has intermediary media, such as pipes, plates or other types of equipment.

## 1.2 Heat Recovery Steam Generator (HRSG)

A Heat Recovery Steam Generator (HRSG) is an energy recovery system that captures and repurposes waste heat from industrial processes, typically from gas turbines, to generate steam. This steam can then be used for various purposes, such as driving a steam turbine in a combined cycle power plant, providing heat for other processes, or supplying district heating systems[8].

The main components of the HRSG are:

a) Economizer: Heats the feed water by using the residual heat from the flue gas, thereby increasing efficiency.
b) Evaporator: Boils the feed water to produce steam using higher levels of heat.
c) Superheater: Further heats the steam to a higher temperature for more efficient use in the turbine.
d) Preheater: Sometimes added to further improve efficiency by preheating the water.

An HRSG operates by channeling exhaust gases from gas turbines through a series of heat exchangers (economizers, evaporators, and super heaters). As the exhaust gases pass through these heat exchangers, they transfer heat to the water, turning it into steam [9]. This steam can then be directed to a steam turbine for additional power generation, effectively increasing the overall efficiency of the power plant. HRSGs are widely used in combined cycle power plants, cogeneration systems, and other industrial settings where large amounts of waste heat are generated. They play a crucial role in increasing the overall energy efficiency and environmental performance of these systems. The heat recovery steam generator (HRSG) scheme is shown in Figure 4[10].
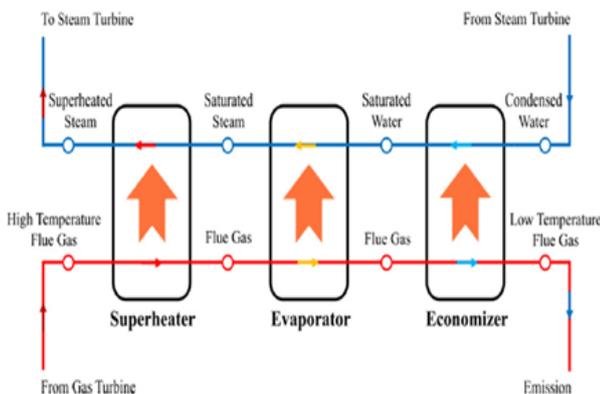


**Figure 4: Heat Recovery Steam Generator (HRSG)**

Benefits of HRSG are:

a) Energy Efficiency: By capturing waste heat, HRSGs increase the efficiency of power plants.

b) Environmental Benefits: Reduced greenhouse gas emissions due to higher efficiency and utilization of otherwise wasted heat.
c) Cost Savings: Reduced fuel costs as waste heat is used, which might otherwise require additional fuel to produce steam.

## II. METHODOLOGY

In this design, we will analyze how much steam can be generated from the GTG flue gas. Aspects studied include:

a) The energy generated in the flue gas both when using natural gas and diesel.
b) Steam that can be produced with this HRSG system both Medium Pressure (MP) steam and Low Pressure (LP) steam.
c) The cost required to generate energy from diesel and natural gas.

This dual fuel GTG has technical specifications power 17,500kW, heat rate 9620 kJ/kW-hr, exhaust flow 205,400 kg/hr, exhaust temperature 480°C and Combution system with SoLoNO$_x$ (DLE) conventional. And typical package dimensions with length 14.2m, width 3m, height 3.9m and package weight approx 87,510 Kg. With a capacity of 3 x 50%, where 2 generators will run simultaneously with 50% load and 1 generator standby position.

To be able to complete the energy balance calculation, we need the necessary data, namely flue gas temperature, ambient temperature, flue gas mass flow rate, specific heat of flue gas and number of moles of constituents. This can be formulated as follows (equation 1):

$$Q = m.Cp.\Delta T \qquad (1)$$

Q $\quad$ = $\quad$ Process Heat, BTU/hr
M $\quad$ = $\quad$ Flow Fluid, lb/hr
Cp $\quad$ = $\quad$ Specific heat, BTU/lb.°F
$\Delta T$ $\quad$ = $\quad$ Temperature difference, °F

The required air mass flow rate can be known by the equation 2:

$$m_o = AFR \times m_f \qquad (2)$$

$m_o$ $\quad$ = $\quad$ Air mass, Kg/s
$m_f$ $\quad$ = $\quad$ Fuel mass, Kg/s
AFR $\quad$ = $\quad$ Air Fuel Ratio

The heat transfer that occurs in the HRSG includes a combination process of conduction, convection and radiation. The heat transfer rate that occurs in the HRSG can be found from the following equation 3:

$$Q = U.A.\Delta LMTD \qquad (3)$$

| | | |
|---|---|---|
| Q | = | Heat transfer rate, kJ/s |
| U | = | Overall heat transfer coefficient, $W/m^2.{}^{o}C$ |
| A | = | Heat surface area, $m^2$ |
| $\Delta$ LMTD | = | Logarithmic temperature difference, ${}^{o}C$ |

While the formula for finding LMTD using the following equation 4[11]:

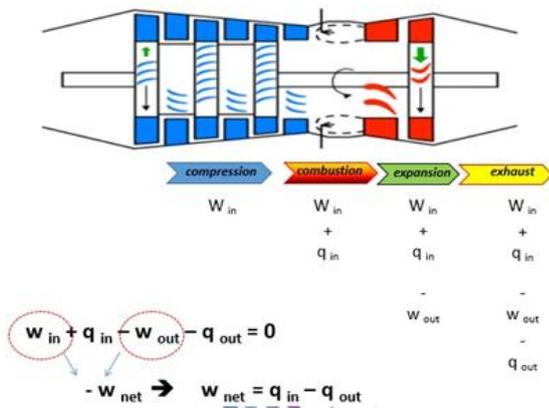| | | |
|---|---|---|
| LMTD | = | $(\Delta th - \Delta tc) / \ln (\Delta th/ \Delta tc)$ (4) |
| LMTD | = | Average temperature, ${}^{o}F$ |
| $\Delta th$ | = | Hot fluid temperature difference, ${}^{o}F$ |
| $\Delta tc$ | = | Cold fluid temperature difference, ${}^{o}F$ |



**Figure 5: Work and Heat Energy Equation**

The Work and Heat Energy Equation is shown in Figure 5, and The amount of HRSG thermal efficiency is defined as the ratio between the rate of energy required for water to become superheated steam and the rate of flue gas energy flow in the HRSG is:

$$\eta \text{ HRSG} = (\frac{Qs}{Qf}).100\% \qquad (5)$$

$$= \left[\frac{(MHP.hHP)+(MLP.hLP)-(MHP+MLP)hin}{(0.9835x(MfgxGHV)-(MWgt)-966.947-LGN)}\right].100\%$$

| | | |
|---|---|---|
| MHP | = | High Pressure Vapor Rate, Kg/s |
| hHP | = | High Pressure Vapor Enthalphy, Kj/Kg |
| MLP | = | Low Pressure Vapor Rate, Kg/s |
| hLP | = | Low Pressure Vapor Enthalphy, Kj/Kg |
| hin | = | Enthalphi of water entering economizer LP, Kj/Kg |
| Mfg | = | Gas Turbine Fuel Rate, Kg/s |
| GHV | = | Fuel Calorific Value, Kj/Kg |
| MW gt | = | Gas Turbine Generator Data |
| 0.9835 | = | Heat consumption loss value |
| 967.13 | = | Gas Turbine loss value |
| LGN | = | Generator Loss = 1.69 MW gt, kW |

To calculate the cost burden when using diesel fuel or natural gas by taking field data related to diesel fuel levels and natural gas flow meters before use by GTG. Then calculate the cost of use and the difference between the two.

## III. RESULTS AND DISCUSSIONS

The gas turbine generator was tested using two different fuels, diesel fuel and natural gas. The data obtained from the test results with GTG conditions made almost the same in order to compare its performance both on fuel and on exhaust heat energy that can be used for HRSG applications. The data can be seen in table 1.

**Table 1: GTG with Natural Gas and Diesel Fuel**

| Parameter | Unit | Natural Gas | Diesel |
|---|---|---|---|
| Gas Producer Rotational Speed | % | 100 | 100 |
| Gas Producer Rotational Speed | rpm | 11170 | 11168 |
| Turbine Rotor Inlet Temperature | ${}^{o}F$ | 2159 | 2111 |
| Power | hp | 23151 | 21459 |
| Generator Real Power | kWe | 16665 | 15447 |
| Heat Rate | Btu/hp-h | 6934 | 7011 |
| Heat Rate | Btu/kW-h | 9634 | 9741 |
| Thermal Efficiency | % | 35,42 | 35,03 |
| Compressor Pressure Ratio | | 19,50 | 19,20 |
| 3rd Stage Turbine Inlet Temperature | ${}^{o}F$ | 1363 | 1321 |
| Exhause Stack Temperature | ${}^{o}F$ | 911 | 883 |
| Air Inlet Mass Flow | pps | 122,10 | 118,20 |
| Exhause Mass Flow | pps | 124,00 | 124,10 |
| Fuel Energy | Mbtu/h | 161 | 150 |
| Gas Fuel Mass Flow | pph | 7624,00 | 118,00 |
| Lower Heating Value | Btu/lbm | 20693 | 18430 |
| Exhause Heat (at 300F and Cp = 0.265) | Mbtu/h | 72,30 | 69,10 |

The same operating conditions in the GTG are shown in the rotational speed values in both fuels, which are around 11170 rpm. The GTG with Natural Gas produces more power (23.151 hp) than when using diesel fuel (21.495 hp), which can support the HRSG better. The higher net electrical power generated due to the use of natural gas will support the HESG better. And the low heat rate results in an efficiency value in energy use[12]. The high flue gas temperature values, both when using natural gas (911${}^{o}F$) and diesel (883${}^{o}F$) are proof that there is still energy that can be used as an HRSG. The higher exhaust heat in natural gas provides a greater opportunity for the HRSG to produce more steam.

GTG with Natural Gas produces higher flue gas temperatures and mass flows than Diesel Fuel. This means that the HRSG in a system using Natural Gas will receive more heat energy from the flue gas, which can increase steam production.Higher flue gas temperatures will allow the HRSG to achieve higher steam temperatures or increase steam

production capacity, which can improve the overall efficiency of the combined cycle system.

GTGs with Natural Gas have a slightly higher thermal efficiency (35.42%) and lower heat rate (9634Btu/kW-h), indicating that Natural Gas is used more efficiently in generating electrical energy than using diesel fuel. This better efficiency reduces fuel consumption to produce the same power, thus having a positive impact on operating costs and emissions.

Natural Gas provides greater exhaust heat, the HRSG will be able to produce more steam that can be utilized for steam turbines or other applications. This increases the additional power generation capacity of the HRSG, making the system more efficient overall. The larger Exhaust Mass Flow of the Natural Gas-fired GTG also contributes to the increased steam production, as the HRSG can capture more heat energy from the larger flue gas flow. The higher LHV value of Natural Gas indicates that the energy per unit mass of Natural Gas is higher than Diesel Fuel. This means that to produce the same amount of energy, the fuel consumption of Natural Gas will be lower, which makes it more fuel efficient in the long run.

The advantage of using Natural Gas compared to Diesel Fuel in GTG, we need to calculate the hourly fuel cost of each fuel based on the price and energy consumption shown in the table. After that, we can compare the two costs to determine the savings.

GTG energy consumption based on the table 1, the GTG energy consumption is Natural Gas 118 MMBtu/h and Diesel Fuel: 117.8 MMBtu/h. If fuel price of Natural Gas is $10 per MMBtu and the price of Diesel is $1.3 per liter. Calculating the energy value of diesel per liter base on table 1, we know that the Lower Heating Value (LHV) of Diesel is 18,430 Btu/lbm (the density of diesel is about 0.85 kg/liter). So, 1 liter of diesel is $0.85 \times 2.20462 = 1.8739$ lbm.

Therefore, the energy per liter of diesel is $18.430 \text{Btu/lbm} \times 1.8739 \text{lbm/liter} = 34.538 \text{Btu/liter}$. GTG energy consumption for Diesel is 117.8 MMBtu/h, or 117,800,000 Btu/h. The number of liters of diesel required per hour is $\frac{117,800,000 \text{Btu/h}}{34,538 \text{Btu/liter}} \approx 3,411.6 \text{liter/h}$. Calculating Fuel Cost per Hour for Natural Gas Cost is $118 \text{MMBtu/h} \times 10\$/\text{MMBtu} = 1,180\$/h$, and diesel Cost per hour is $3,411.6 \text{liter/h} \times 1.3\$/\text{liter} = 4,435.1\$/h$. Calculating the hourly advantage of using Natural Gas over Diesel per hour is:

= Diesel cost per hour-Natural Gas cost per hour
= 4,435.1-1,180=3,255.1$/h

## IV. CONCLUSION

GTG with Natural Gas tend to perform better than Diesel Fuel in terms of thermal efficiency, output power, and contribution to the HRSG. The higher flue gas temperature and mass flow allow the HRSG to produce more steam, thereby increasing the efficiency and total output power of the combined cycle power generation system. From an operational perspective, the use of Natural Gas is more advantageous as it provides better fuel efficiency, lower emissions, and increases steam production in the HRSG, which can reduce reliance on supplemental fuels. Natural Gas, with its advantages in efficiency, heat rate, and contribution to the HRSG, is a better choice to maximize the output of the combined cycle power generation system. By using Natural Gas as fuel for the GTG, there will be a saving of approximately $3,255.1 per hour compared to using Diesel Fuel.

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