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SIMULINK MODELLING OF COMBINED CYCLE GAS TURBINE (CCGT) POWER PLANT FOR PERFORMANCE ANALYSIS

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ABSTRACT

A gas-fired plant and a steam-fired plant make up a combined cycle power station. The purpose of this research is to build a CCGT power plant and investigate the interaction between fuel and airflow using a simulink model. A mathematical model is used to predict how the CCGT power plant system will react. The goal of a turbine is to extract as much energy as possible from the working fluid and convert it into usable work. A large amount of heat energy from the gas turbine exhaust is wasted but has a lot of potential energy. The term total energy approach describes a system's capacity to use all of the energy at its disposal. To generate as little energy waste as possible, every watt of heat energy in a power system is supposed to be used to produce work, steam, or heat air or water. The creation of a mixed-cycle power plant is the most efficient and cost-effective way to accomplish this objective. The concept and early development of the mixed cycle were centred on the utilisation of thermal power plant waste heat. The temperature of the gas turbine exhaust can vary from 450°C to 650°C depending on the pressure ratio and turbine input temperature. It is wasteful to discard this energy into the environment. This wasted heat energy could be used to generate steam in the steam heat recovery generator (HRSG). By employing the Rankine cycle to expand the steam generated by the HRSG in a steam turbine, additional power may be created. One name for this configuration is a gas/steam mixed-cycle power plant. A gas turbine's exhaust temperature must be higher than 570°c. For the steam cycle to function properly and for the combined cycle efficiency to remain high.

Keywords: combined cycle gas turbine (CCGT), dynamic model, turbine, combinedheat and power (CHP), efficiency.

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INTRODUCTION

Numerous studies have been done on how the world's energy demand is increasing. Various factors have been connected to such an increase. For instance, urbanisation, rapid population increase, and economic expansion were all connected to rising energy demand by Kumar *et al*. (2007). In the literature, there are several instances of similar points of view (e.g. Nayak&Mahto, 2014; Rai *et al*. 2013; Jassim, *et al*, 2015). A crucial component of the world's energy production industry is CCGT power plants. For instance, Rai.,*et al.* (2013) asserted that CCGTs were crucial in increasing electrical production and the existence and ongoing development of society depended critically on electrical energy. Studies like Nayak and Mahto's (2014) study, which indicates the continual rise in energy demand, may provide additional proof of the significance of power generation.

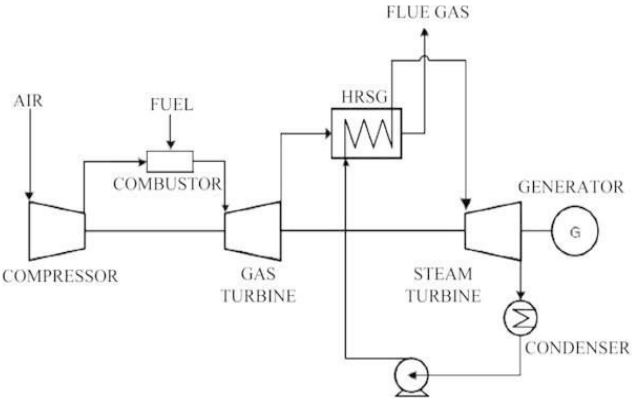

Figure-1. Schematic Illustration of a CCGT.

Using two thermal cycles instead of one increases the efficiency of a single power plant. Since the 1970s, energy use has gradually increased. A single-shaft power plant cannot meet the massive energy demands of the modern world. Because of the combustion chamber losses, which are typically 29% higher in gas-fired facilities than in coal-fired ones, they are less efficient. Combination cycle power plants can reduce their emissions thanks to their improved efficiency. When a gas-fired power plant is combined with a steam-fired one, overall power plant efficiency is raised. Coal and steam power plants make up about 36% of the total efficiency in a combined cycle. The steam section of a CCGT power plant could require 2.5 to 3 hours to heat up. Within ten to thirty minutes, the steam component can maintain the system and meet the peak demand. The Rankine cycle, which uses a steam turbine, and the Brayton cycle, which uses a gas turbine, are the two cycles that make up CCGT and boost the total plant efficiency (Nayak&Mahto, 2014; Tiwari, Islam, & Khan, 2010; Ibrahim & Rahman, 2012). Rai *et al.* show that CCGT fared better than GT in terms of improvement (2013). In this particular case, it is claimed in their study that collecting some of the steam turbine's low-quality thermal energy derived from the exhaust gas can raise the gas turbine's efficiency, which ranges from 28% to 33%, to around 60%. The benefits of efficiency have led to the widespread use of CCGT. For instance, Mattos et al. (2016) found that combined cycle power plants have excellent thermal efficiency values when compared to other existing designs, which explains why CCGT has been frequently used to generate electricity. Studies show that they can be identified by superior thermodynamic, economic, ecological, and operating indices (e.g., Dev, *et al*, 2015). Modelling of CCGT power plants is becoming increasingly important for examining the dynamic performance of power networks as combined-cycle power plants are used more frequently (Mello *et al*., 1994). For nations where CCGT plants make up a sizable share of the country's power-generating capacity, this demand is particularly acute. The dynamic performance of this plant depends on several factors, including controls. The contributions provided in this work will have a substantial impact on the modelling of both current and future installations.

THERMODYNAMICS CCGT

The gas turbine's airflow is indicated as follows:

$$W = W_a \frac{Pa}{Pao} \frac{Tio}{Ti}$$

Where Pa stands for atmospheric pressure and Ti for the ambient temperature.

The temperature of the compressor discharge is indicated as

$$T_d = T_i\left(1 + \frac{x-1}{\eta c}\right)$$

$$X = (\text{Pro } w)^{\frac{\gamma-1}{\gamma}}$$

$\boldsymbol{\gamma}$ is the specific heat ratio, and Pro is the intended pressure ratio of the compressor.

The inlet temperature of gas turbine T_f (K) is provided by [11]

$$T_f = T_d + (T_{fo} - T_{do}) \frac{Wf}{W}$$

Where Wf represents the fuel flow by its rated value, "o" stands for the rated value, W for airflow, and Td for the temperature of the discharge of the compressor.

Te (K), the temperature of the exhaust from a gas turbine is offered by [11]

$$T_e = T_f[1 -(1 - \frac{1}{x}) \eta_t]$$

Where the turbine efficiency is ηt. The airflow and exhaust gas flow are nearly equal.

According to Horlock [6], a combined cycle's efficiency (unfired) is stated as

$$\eta_{cc} = \eta_{gt} + \eta_{st}(1 - \eta_{gt})$$

Where the combined cycle efficiency is denoted by η_{cc},the steam Turbine efficiency is denoted by $\eta_{st}$and the gas turbine efficiency is denoted by $\eta_{gt.}$

SIMULINK MODELLING OF CCGT

In recent decades, many models of gas turbine behaviour have been developed. Rowen presented the basic equations (Rowen Model II) [4-5] for simulating a single-shaft gas turbine as early as 1992. The technical brochure on gas turbine and steam turbine modelling for CCGT power plants is summarized in this document. There may be additional models of this kind in simulation programs. A CCGT model's operation is depicted in the diagram (Figure-2) below, which clearly states the flows and operations.

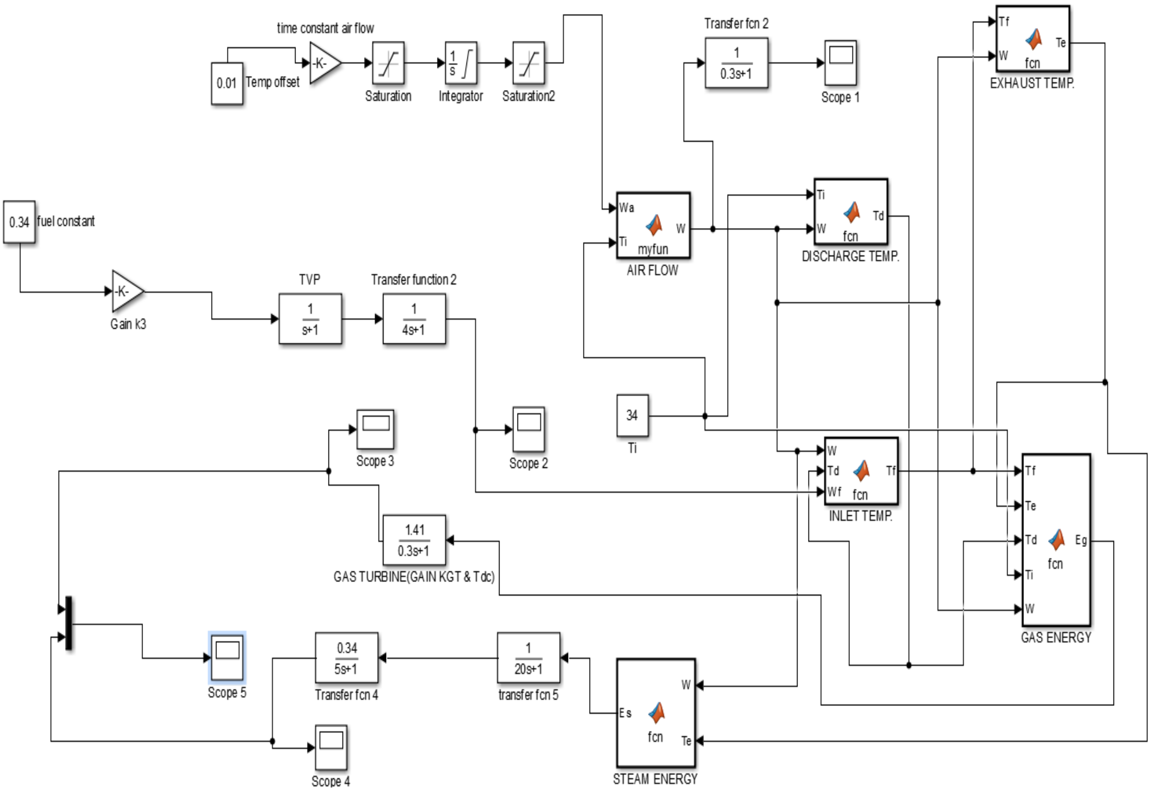

Figure-2. Simulink Model of Combined Cycle Gas Turbine.

Figure-2 depicts a dynamic model of an integrated gas turbine. The Simulink model contains multiple blocks defining various parameters that need to be evaluated to optimise the CCGT. A variety of various blocks are used to control the speed and load of the GT, the waste heat recovery boiler, or ST, the temperature transducer, and the rotor shaft. Rotor speed variation (1-N) and a reference load must be considered to determine the fuel supply (Fd).Overheat control regulates the gas turbine's exhaust temperature (Te^{o}C) (temperature control block). In gas turbines, air control increases the exhaust temperature to the appropriate level while keeping the temperature offset properly below a reference level by modifying the airflow. Table-1 lists every parameter that was used in the model.

Table-1. System Parameters.

Parameters	Measured value
1. compressor air inlet temperature (T_i)	34°C
2. fuel flow rate (W_f)	348.77771 m^3/h (15MW)
3. Gas turbine inlet temperature (T_f)	512°C
4. Air flow rate (W_a)	1.016 bar
5. Exhaust temperature (T_e)	336°C
6. Compressor efficiency	0.85
7. Turbine efficiency	0.85
8. compressor discharge temperature (T_d)	125°C
9. Air control upper limit	1
10. Air control lower limit	0
11. Temperature control upper limit (T_{max})	1.1
12. Temperature control lower limit (T_{min})	0
13. Ratio of specific heat (γ)	1.4

RESULTS AND DISCUSSIONS

a. Air-flow system

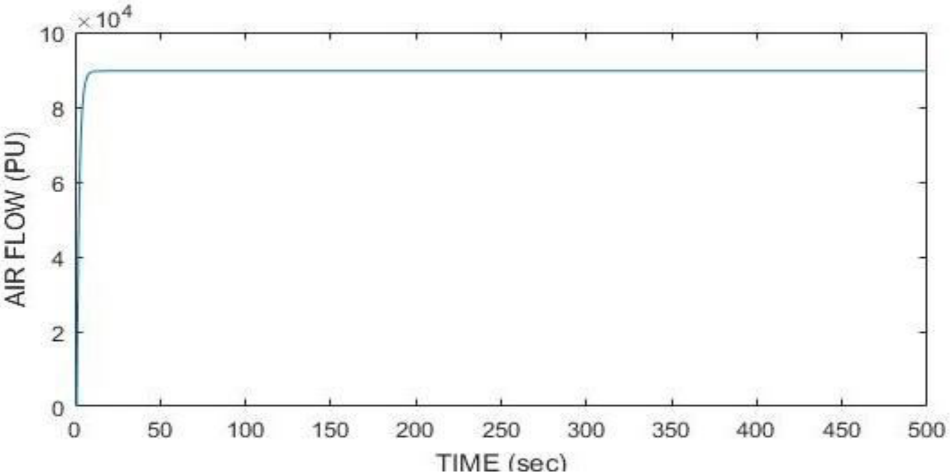

Figure-3. Air flow vs time curve.

It has been noted that the airflow increases exponentially over time in the previous graph (in sec). By using a compressor to boost temperature and pressure, the air is compressed.

b. Fuel flow system

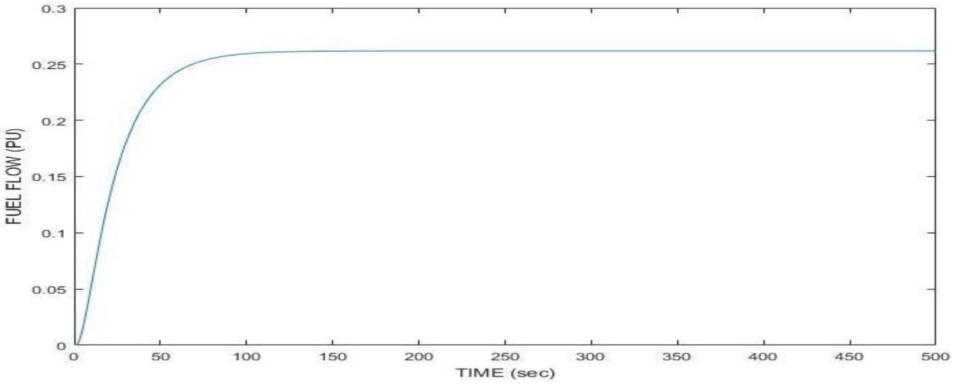

Figure-4. Fuel flow vs time curve.

In the graph above, the fuel flow increases exponentially over time. Pressure valves control the flow of gasoline in the system.

c. Gas turbine output

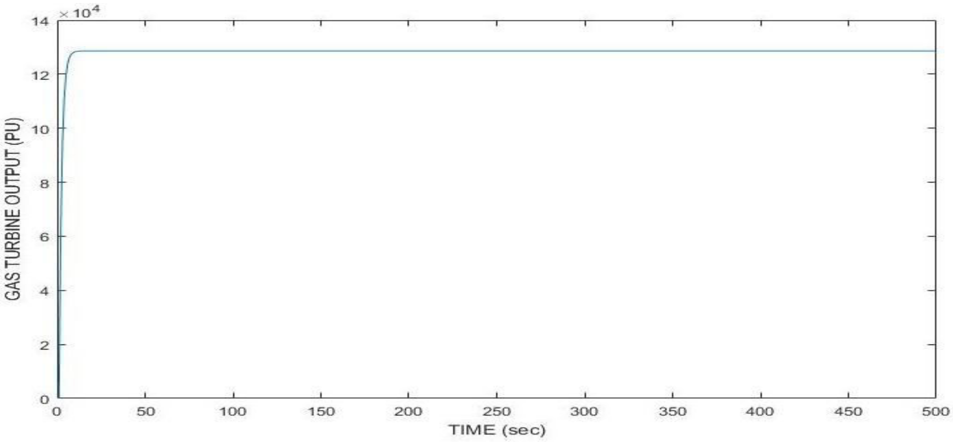

Figure-5. Gas turbine output.

In the graph shown above, the output of a gas turbine increases exponentially over time.

d. Steam turbine output

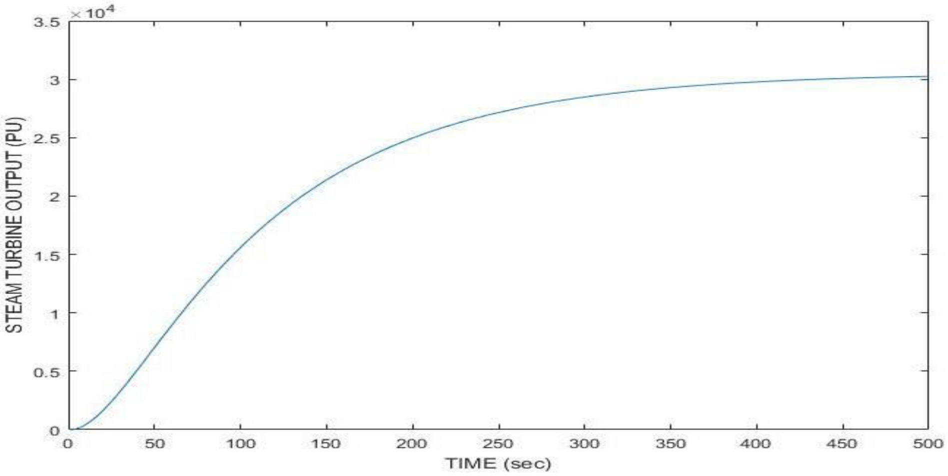

Figure-6. Steam turbine output.

The steam turbine power plant's output is seen in the graph. HRSG is used to supply the economizer with the exhaust temperature of the gas turbine. In seconds, the graph shows a rise in time.

e. Combined power output

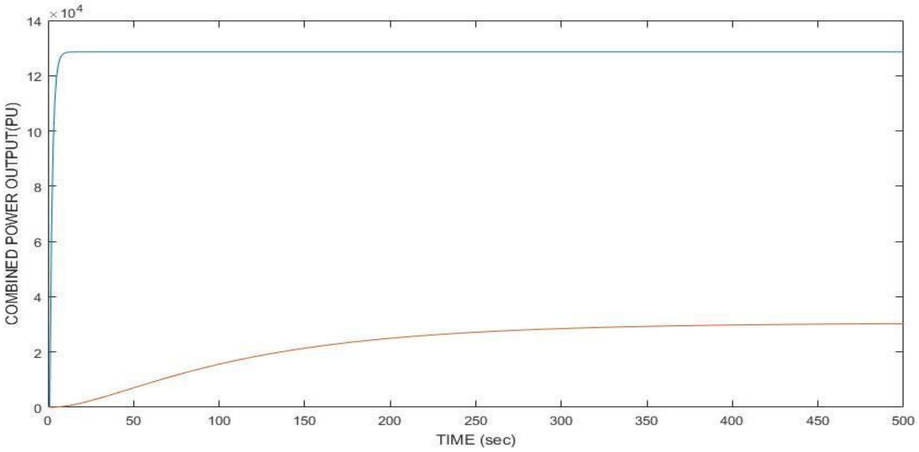

Figure-7. Combined power output.

The output of the CCGT power plant increases the response time of the steam turbine and the gas turbine. The steam turbine produces 30 MW, and the gas turbine 130 MW. The plant can produce 160 MW in total.

CONCLUSIONS

The most typical sources of mechanical power generation are steam and gas turbines. Large-scale electricity production is possible with the use of steam and gas turbines. Steam turbines are thermally more effective than gas turbines, nevertheless. The peak cycle temperature ratio can be raised by raising gas turbine intake temperatures and decreasing compressor inlet air temperatures. A greater gas temperature (exhaust) is caused by a larger cycle peak temperature ratio, which raises stack energy loss.The primary objectives of the CCGT power plant model are to boost plant productivity and make up for system losses. Both the gas turbine and the steam turbine use the heat that is transported to the Heat Recovery Steam Generator (HRSG) from the exhaust of the gas turbine.

SCOPE OF FUTURE WORK

Detailed evaluation can be done for the performance analysis of the combined cycle gas turbine power plant with the actual operational data.

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