DYNAMIC DESIGN ANALYSIS AND NUMERICAL MODELLING SIMULATION OF AFAM VI POWER GAS PLANT

Samuel H. Kwelle[1] Nnadikwe Johnson[2] Chuku Dorathy E. Jerry [3] Ewelike Asterius Dozie [4]

[1]Department of Petroleum and Gas Engineering Imo State University, Owerri, Nigeria

2 First Independent Power Limited, Rivers State, Nigerian

[3] H.O.D department of Agriculture and Environmental Engineering, Imo State University, Owerri, Nigeria

[4]Department of Petroleum and Gas Engineering Federal University Otuoke Bayelse State

ABSTRACT

An investigation into the modeling and simulation of the Afam VI Gas Power Plant is included in this article. Recently, there has been a noticeable increase in the demand for energy in the developing world. Thus, it is vital to employ power generators that have high efficiency and specific power production, low discharges of contaminants, and relatively low operating cost for a potential use of accessible fuels. The use of industrial gas turbines is a tried and true method of producing electrical power. As a result, it is now guaranteed that the gas turbine power plant will hold a major role within the world's electricity systems. Studies on system reliability demand accurate representations of the components of power systems. The gas turbine, speed regulator, and exciter are crucial components of the generators. A thorough block model is created after first determining the transfer functions of the various turbine components. In addition to the turbine, the excitation system, which comprises of a synchronous generator, a transformer, and an IEEE AC7B type power system stabilizer, is modeled. This model is then modified for usage with the brand-new Afam vi Gas Power Plant (AGPP) in the Niger Delta Area using data directly derived from the specifications of BGPP makers. Nigerian For the simulation, the station has a load assigned to it. Simulation is used to study both major signal disturbance events, such as line-to-ground and three-phase faults, and minor signal disturbance scenarios, such as a step shift in governor input. Only a few of the system variables that are gathered and graphed at each stage include rotor angle, accelerating power, terminal voltage, and rotor speed. Relevant advice is given in light of the findings.

Keywords-gas turbine model; exciter AC7B; power system stabilizer (PSS2B); power system stability; Afam vi gas power plant

I. INTRODUCTION

A study by International Energy from 2004 predicted that during the ensuing two decades, the world's net power consumption will increase continuously and finally double [1]. One of the best and most well-established technologies for generating electricity is the heavy-duty gas turbine.

Gas turbines may provide transient operations because of their capacity to start, increase and decrease loads, and unexpectedly shut down, which can lead to system instability over time. In order to gain a better understanding of the turbine dynamics, these ad hoc circumstances need to be investigated. In order to simulate the turbine system under a variety of operating situations, a mathematical model must be constructed. Since they provide mechanical energy for transportation, power plants, and factories, gas turbines are an integral element of the global industrial sector. Stationary gas turbines that can run on a variety of fuels such diesel, natural gas, synthetic coal gas, and others have been developed in response to the rising need for reliable electricity.

For better monitoring and management of these complex devices, a full analysis for transient operation prediction utilizing numerical description is required. Gas turbine operations may eventually result in downsides due to start-ups, changing loads, and unplanned shutdowns. Examining these ephemeral circumstances is necessary to comprehend the dynamic behavior of the turbine.

Improving gas turbine dependability, safety, and efficiency is a primary motivation for the development of the model presented in this work.

It was necessary to simulate each component of the gas turbine plant individually. This included the compressor, combustor, turbine, fuel source, and electrical power generation. The compressor works to compress the incoming air, while the recuperator uses the heat from turbine's engine exhaust to preheat the air.

When comparing the anticipated plant production to the actual one, diagnostic procedures established by the model negate the need for superfluous gear. The requirement for plant or system maintenance may be decreased while boosting overall safety [2] by the development of a mathematical model and diagnostic planning which can effectively identify and inform system management that an issue exists.

Il. CONCEPTUAL FOUNDATIONS OF GAS TURBINES

Three main ideas [3, 4, 5] are necessary to get a complete understanding of the gas turbine and its workings.

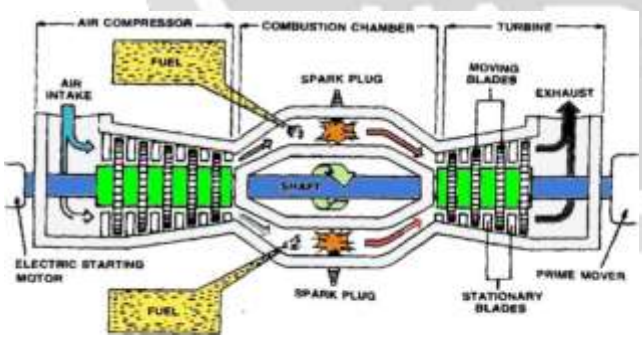
a. compressor,

b. Combustor, and

c. turbine.

Two are mechanical motors, while the third is a heat-adding appliance. Typical HDGT and its main component are shown in a schematic form in Fig. 1 [4].

A turbine is any device that produces power by rapidly spinning fluid. Common fluids include things like air, wind, water, and steam [3]. Compressed, hot air is passed through a set of revolving blades and stationary rings to create energy in a gas turbine (the rotor). It takes a compressor to boost the working fluid's pressure, which is essential for growth. Axial or centrifugal compressors are frequently used due to the larger working fluid volume and speed requirements. The turbines push the compressor, which is affixed to the shaft. As a result, the compressor, combustor, and turbine are the three distinct components that make up a gas turbine [5].



HOW THE SYSTEM OF A GAS TURBINE OPERATES

Figure I. A diagrammatic representation of a typical HDGT and its most important parts[4]

While the gas turbine is running, the first set of compressor blades collects air from the surrounding area. Due to the mechanical power the moving fluid has obtained from the compressor, it is subjected to a rapid rise in pressure and temperature when it reaches a critical mass. The combustion chamber, a component of the boiler that combines the supplied air with the fuel, causes combustion, and generates high-temperature flue gases, is where air is carried when the atmospheric conditions are ideal. After combustion is complete, the flue gases are routed into the turbine, which transforms the kinetic energy of the gases into mechanical rotational power to drive the compressor and supply backup power to spin machines or produce thrust [6]. The phrase used most frequently for rotating machinery is "turbo machines." The flue gases are discharged into the atmosphere by the exit nozzle [6]. Oil or natural gas can be used to power gas turbines [5].

Gas turbine dynamic behavior investigations need a model, and Fig. 2 depicts the Rowen's model for HDGT in a power production system [8].

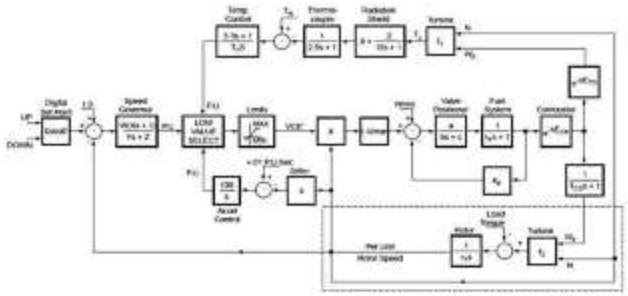


Figure 2. Rowen's HDGT Model [8].

The main representations of the turbine features in Rowen's notion are the transfer functions, fl and f2. Compressor discharge is tied to combustion time delay (TCD), and exhaust gas transport is related to delay dynamics (LD). The functioning of this block causes the turbine exhaust temperature, and its integral gain fl is a result of Wf and N, as indicated in (l). The gas turbine's output torque is a function of Wf and N, and the transfer function p is written as (2) [8]. The mechanical torque of the turbine is represented as (3), which drives the generator [9]. The generator's actual power output is N times this value.

$$F_1 = T_e = T_r - 700*(1-W_f) + 550*(1-N) \quad (1)$$

$$F_2 = T_{mec} = 1.3*(W_f - 0.23) + 0.5*(1-N) \quad (2)$$

mec‾ mec (3)

N is the spinning speed, WF fuel stream, T_{mec} mechanical torque, and P*mec* mechanical power, where T_r is the base temperature.

The typical example of Rowen's concept having a single spindle gas turbine is represented in Fig. 3 [10].

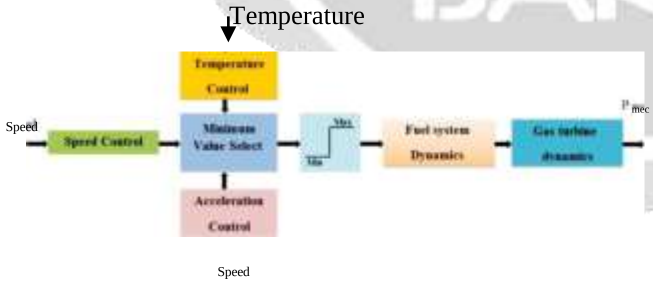


Figure 3. Reduced complexity of Rowen's HDGT model[IO].

For reference, Table I [5] lists the values of the parameters used in the block diagram seen in Fig. 2.

TABLE 1.PARAMETERS OF GAS TURBINES [5]

Parameter	Description	Value	Unit
	Gain = l/ droop (pu MW / pu s eed)	16.8	

x	Constant Lead Time for Speed Regulation (s)	0.7	S
	Constant speed control lag time(s)	1.1	S
z	Mode of Speed Control(l=droop, O=isochronous)	1	
MAXIMU	Request maximum limit (pu)	1.6	Pu
MINIMU	Request minimum limit (pu)	-0.2	
a	positioner of valves	1	
b	Time constant of the valve positioner	0.06	S
c	positioner of valves	1	
min	Minimum fuel intake	0.24	
	Constant fuel time(s)	0.5	S
	System of fuel feedback		
Parameter	Description	Value	Unit
	Delay in combustion (s)	0.02	s
ETD	delay between the turbine and exhaust (s)	0.05	s
CD	Constantcompressordischarge time(s)	0.3	s
	Rated exhaust temperature (^{O}F)	1167	
	Reference Temperature rate (^{O}F)	451	
	TX=TR-700*(1-WF)+550*(1-N)		
	1.3*(WF-0.23)+0.5*(1-N)		
	Inertia = 2*H	13.9982	MWs/ MVA

The overall control system of the gas turbine is composed of three different control schemes: a) speed control, b) temperature control, and c) acceleration control. Below are thorough explanations of each.

A. Regulating Pace

It becomes one of the most important control strategies under typical operating conditions by integrating a temperature controller, an acceleration controller, and its managed variable, the fuel demand. These three independent controllers' outputs are fed into a minimal gate, which determines the least amount of fuel necessary to satisfy each of the three needs. The gas turbine system starts to run as soon as it obtains the fuel required. The main responsibility of the speed governor is to control the amount of power generated by modifying the fuel system's valve settings [11].

B. Regulation of Temperature

The temperature can be changed if there is a problem. The minimum gate receives an input based on the observed exhaust temperature from thermocouple merge radiation shields [12] placed around the turbine's exterior exhaust surface. The control system then compares the demand value to the set point temperature coming from the exhaust of the turbine. The difference between the two readings is the temperature inaccuracy. If the temperature error is larger than zero, the control system will signal that the fuel valve has to be opened [11].

C. Regulating Rates of Acceleration

When operating circumstances become abnormal, the acceleration control system is activated. To accomplish both of these goals, this control setup makes use of feedback.

1. Improving damping is the main objective of creating a supplementary stabilizer term in a speed control system.

2. In the event of a load rejection, to avoid speeding [11].

Ill. THE EXCITER SYSTEM (AC7B)

An exciter system's main objective is to produce direct current (DC) for a synchronous machine's field windings. By adjusting the system's field voltage and current, the exciter system also carries out its fundamental control and protection functions. The generator's immediate and short-term capabilities must be shared by the exciter system in order to respond to transient dynamics with field forcing. To regulate voltage and enhance grid stability, the exciter system should be easily accessible. If it can respond quickly to an interruption, transient stability may be improved. Additionally, it need to be able to modify the producing field to improve the stability of tiny signals [13].

The excitation mechanism used by BGPP is of the AC7B type, as can be observed in Fig. 4. The IEEE Task Force advises using an excitation system similar to the AC7B. Actuals for the excitation system are taken from manufacturer specifications. The generator's field is protected by a VFEMAX exciter current limiter, and the BGPP excitation system also includes a proportional integral derivative (PID)-based alternator voltage regulator (AVR) [14].

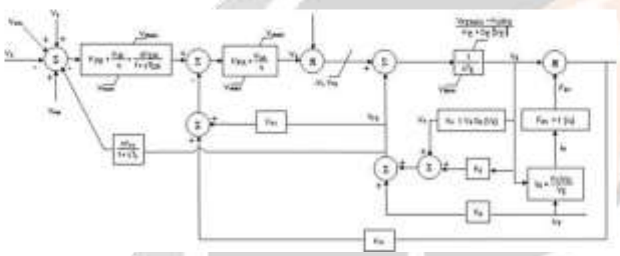


Figure 4. Type AC7B—The exciter system [14]

IV. STABILIZER OF THE POWER SYSTEM (PSS2B)

The power system stabilizer (PSS) provides an additional input signal to the exciter system in order to enhance the power system's damping through exciter management. Variations in rotor speed, acceleration power, and frequency are examples of typical input signals. Power system dynamics may be enhanced by managing the exciter system using stabilizing signals [13].

The PSS used in BGPP is of the PSS2B sort, as can be seen in Fig. 5. The PSS2B's real specifications were taken directly from the product's specification sheets. A combination of power and speed or frequency is used to provide the stabilizing signal for the PSS2B type PSS [14].

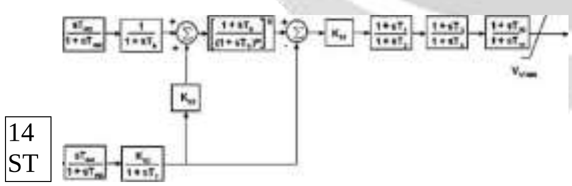


Figure 5. Type PSS2B [14]

V. AFAM GAS POWER PLANT MODELING

It is crucial to model and simulate gas power plants utilizing system controllers in order to properly understand their dynamic features. Algebraic and differential equations that may be modelled using a variety of blocks in a simulation platform are frequently used to describe the linear and nonlinear behavior of a system [15].

The high-output, single-shaft BGPP gas turbine is utilized in industrial settings. As a result of the station's four gas turbines, it has a theoretical capacity of 500 MW and a practical capacity of 460 MW. The electrical requirements for the synchronous machine are listed in Table Il.

Parameter Description	Value	Unit
Type		9A5
Specified apparent power(SNgen)	142	Mva
Voltage of the rated stator (Un)	15	
The rated frequency (fn)	50	
Power factor rated (p.f.)	0.85	
Maximum speed (Wm)	3000	mm

TABLE 11.MACHINE DATA IN SYNCHRONY

Step-up transformers are used in the electrical model of BGPP to raise low voltages to higher levels before power is transmitted through transmission lines.

In Table III, you'll find the transformer's technical specifications.

TABLE III.TRANSFORMER STEP-UP DATA

Parameter Description	Value	Unit
Type YNd11	3 - phases	
Rated- apparent power (Snt)	150	Mva
Rated- primary voltage	15	Kv
Rated- secondary voltage	132	Kv
Rated (shon circuit) impedance at central tap (step up transformer rated aarentowerZsc	0.125	p.u.
Xsc/Rc Ratio	50	(default value

A. Model of a Gas Turbine System

A block-based dynamic model of a fundamental gas turbine was constructed for this study, as shown in Fig. 6. The gas turbine system is made up of the controller for the gas turbine (shown in Fig. 6), a set of algebraic equations that describe the steady-state thermodynamic parameters of the gas turbine, time delays, and a few important controls. For the typical gas turbine system parameters, Table I is reviewed.

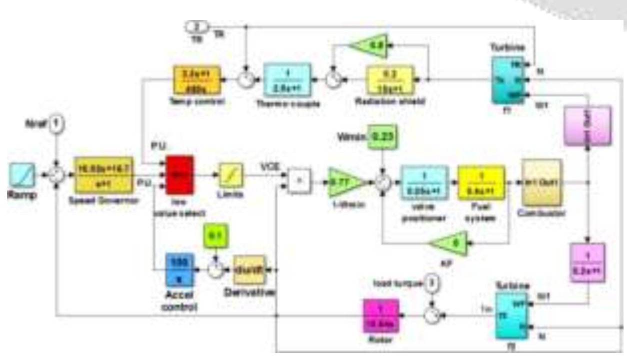


Figure 6. Controller model for a simulated gas turbine [14]

Fig. 7 displays the exhaust air temperature from the model BGPP gas turbine. On the other hand, Fig. 8 and a real-time log of the exhaust temperature variation over time [5] can be contrasted. One possible observation is how close together the two figures are. This illustration demonstrates how the gas turbine system model has been validated in practice.

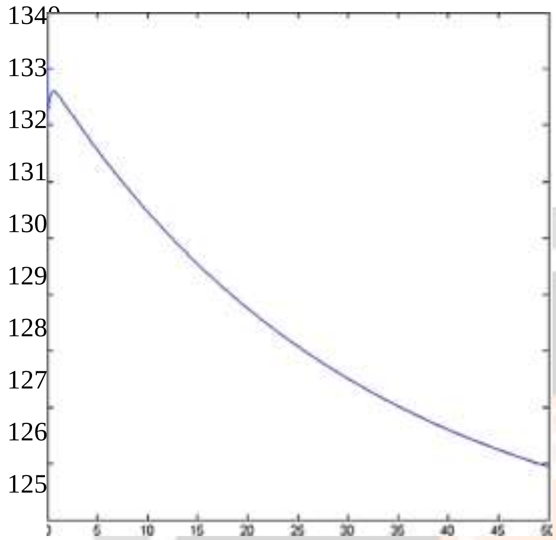


Figure 7. Predicted Exhaust Temperature for Gas Turbines.

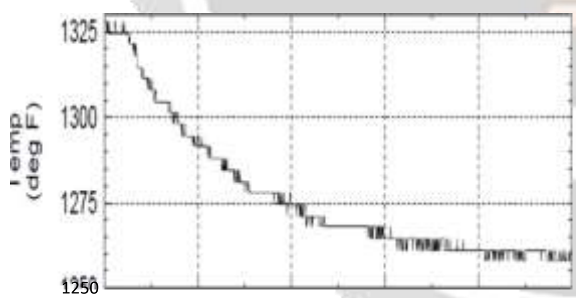


Figure 8. Temperature of the exhaust when the measurement was taken from [5].

B. Model of the Exciter System

In Fig. 9, we see the simulated model of the AC7B type exciter in BGPP. Typical exciter system specifications are picked out of the manufacturer's specs.

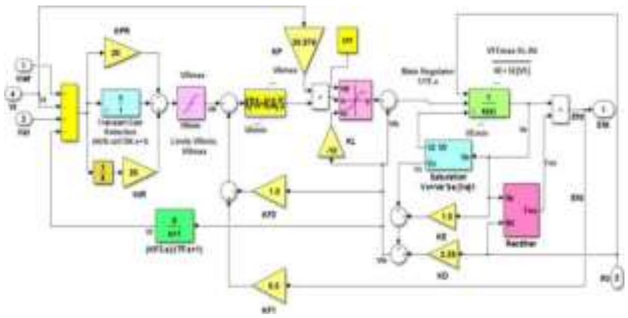


Figure 9. Exciter AC7B simulation [14]

C. Model of the PSS

Fig. 10 depicts the PSS2B simulation model used in BGPP. The PSS model's default settings are taken directly from the manufacturer's documentation.

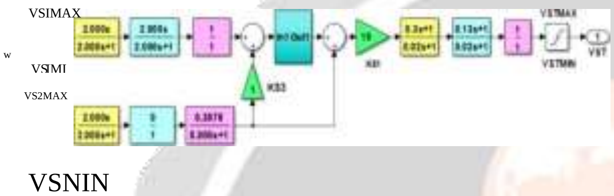


Figure 10. PSS2B simulation [14].

VI. STUDIES OF SIMULATION

Dynamic system models of the parts of the power system are used to simulate the electromechanical behavior in the presence of disturbances. To develop the appropriate operational conditions and secure operating limitations, such simulations are essential for system planning.

In order for the system to work, mechanical kinetic energy must be converted from the electric power flowing through it to the mechanical power at the spinning generator. Following disturbances, oscillations may be seen in a variety of parameters, with the rate of power flow acceleration being the most significant. It illustrates the point at which the mechanical inputs and electrical power output are equal.

The created model is subjected to several simulations with various perturbations. A single line-ground failure, a three-phase fault at BGPP, and an abrupt change in the controlling input are frequent scenarios used in power system simulations. Each stage includes the recording and graphing of the terminal voltage (VT), acceleration power (Pacc), and rotor speed (Wm).

Figure 11 depicts the BGPP model as a whole, with its four units, while Figure 12 depicts the model details for a single unit.

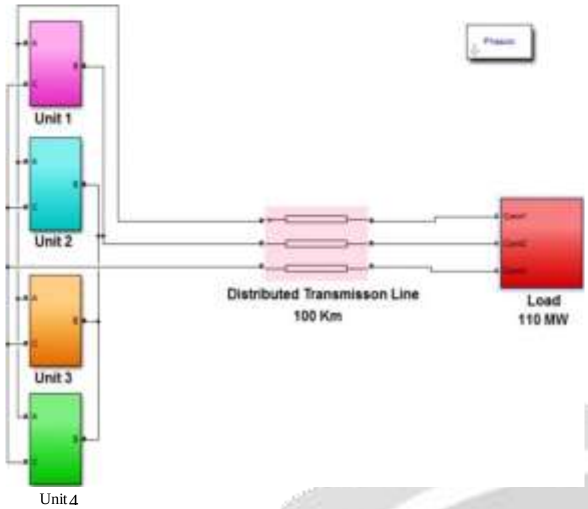


Figure ll. The BGPP model for four units.

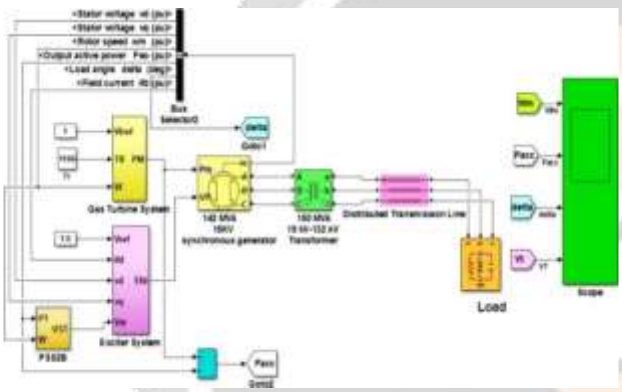


Figure 12. The model for a single unit (uniti in Fig. 11) of BGPP

A. A. First Case Study

Here, we briefly alter the rotor speed of the BGPP to see the results. The throttle control of the gas turbine is changed accordingly. 5% of the reference step is adjusted. The system's behavior in response to this minor disturbance is shown in Fig. 13. According to the data, a 5% increase in rotor speed corresponds to an increase in terminal voltage, rotor angle, and rotor speed. The system can be returned to its steady condition by resetting the governor and exciter.

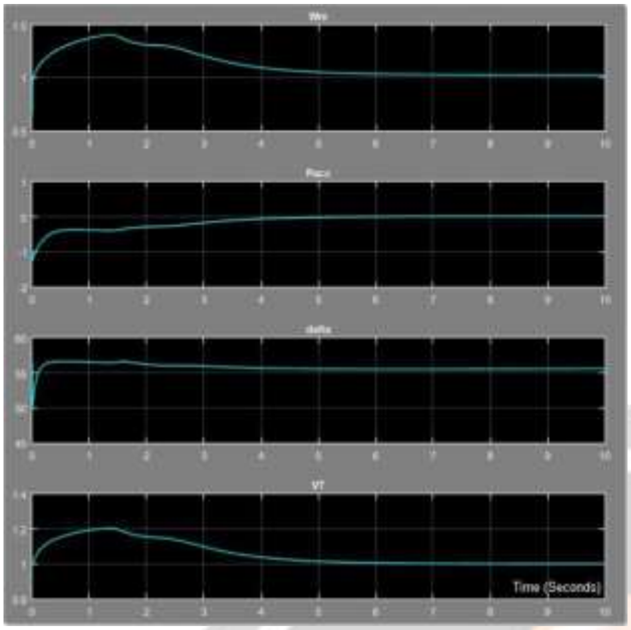


Figure 13. BGPP with a little disruption after a 5% speed step.

B. Second Case study

At time t=5s, the BGPP transmission line has a single-phase breakdown and is terminated. The behavior of the system in this situation is shown in Figure 14. The outcomes of the simulation demonstrate that the system possesses desirable dynamic features and that, following a brief transient, the system variables converge to their values.

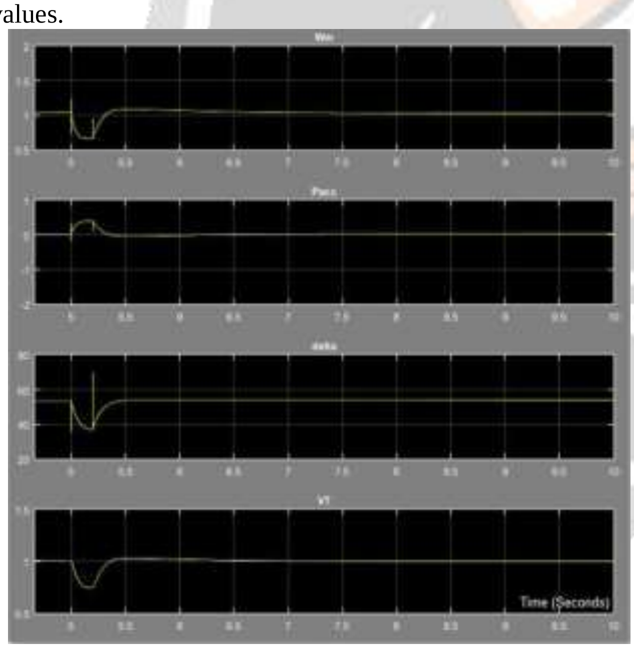


Figure 14. When applied at the end of the transmission line for BGPP, one phase fault occurs at t=5s..

C. Third Case Study

In this instance, the BGPP transmission line is terminated with a three-phase fault. At t=5s, the three-phase fault is triggered, and at t=5.2s, it is resolved. Figure 15 depicts the system's reaction in this particular case study. As the rotor speed approaches zero, the rotor angle (delta) also approaches zero. Since the electric power output (Pe) drops to zero as a result of the malfunction, the acceleration power (Pac c) climbs to 1 pu. FIGURE 16 is a magnified version of FIGURE 15. After such a shock, the system may recover.

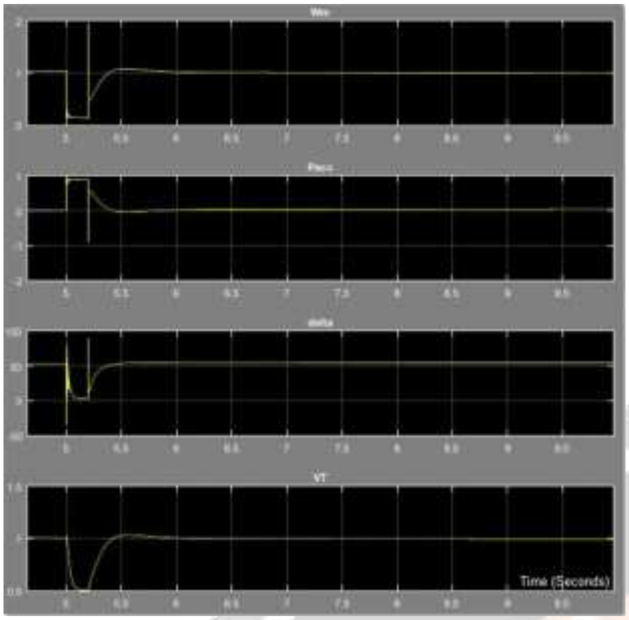


Figure 15. When t=5s, a 3-ph fault occurs at the end of the transmission line for BGPP..

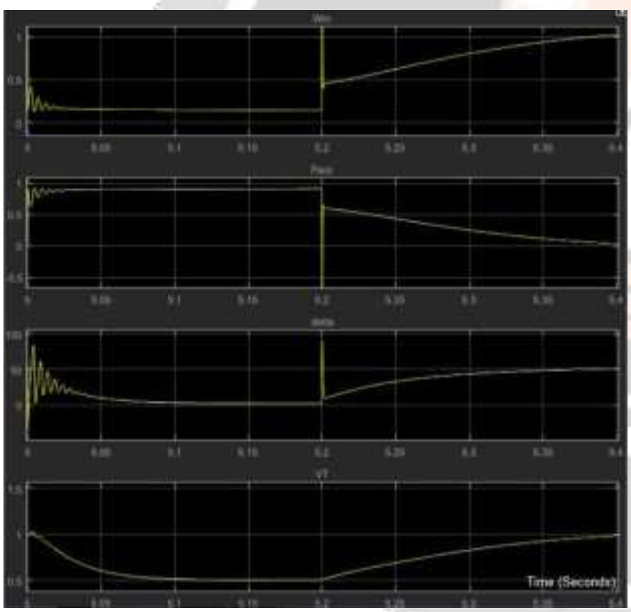


Figure 16. In Fig. 15, zoom in on the duration of a three-phase fault when applied at the end of a transmission line for BGPP.

VII. CONCLUSIONS

The Afam vi Gas Power Plant modeling and simulation results are presented in this work. From the product specification documents that each manufacturer provides, realistic system component data is derived. A tentative inference is made from the simulation results regarding what occurs to the Afam vi Gas Power Plant when different disturbances are put into the system. Additionally, the following issues are briefly touched on:

1. Who is interested in learning more about the HDGT and BGPP dynamic model's foundational elements? It is intended that this material would serve as a primer for pupils.

2. The system is capable of effectively damping off the low frequency oscillations that would otherwise occur when a little disturbance is applied.

3. In a fair amount of time, BGPP can recover from a one-phase failure or a three-phase fault and restore regular operation. This shows that the system controller is working properly and can successfully stop oscillations to get the system back to how it should be running (speed control, exciter system AC7B, and PSS2B).

AKNOWLEDGEMENT

The authors would like to extend a special thank you to the Johnson and Sylvester Centre for African Research Engineer Library for their assistance in utilizing the center's equipment to actualize our comprehensive results. All praise belongs to Almighty God, the most merciful and beneficent, for having blessed the authors.

REFERENCES

[1] R.K. Sullerey and Ankur Agarwal "Performance Improvement of Gas Turbine Cycles" Advances in Energy Research (AER -2006).

[2] R. Sekbon, H. Bassily, 1. Wagner, Ph. D., P.E., and Gaddis, Ph.D. " Stationary Gas Turbines- A Real Time Dynamic Model with Experimental Validation " Proceeding of the 2006 Amercan Control Conference, Minneapolis, Minnesota, USA, June 14-16, 2006 IEEE

[3] LeSe S. Langston, University of Connecticut and George Opdyke, Jr., Dykewood Enterprises "Introduction to Gas Turbines for NonEngineers" Published in the Global Gas Turbine News, Volume 37: No. 2, 1997

[4] Mohammad Reza Bank Tavakoli, BehroozVahidiSesior Member IEEE, and Wolf gang Gawlik " An Educational G~id to Extract the Parameters of Heavy Duty Gas Turbines Model in Dynamic Studies Based on Operational Data" © 2009 IEEE.

[5] A. K. Raja, Amit Prakash Srivastava and Manish Dwivedi " Power Plant Engineering " © 2006 New Age International (P) Ltd., Publishers, Published by New Age International (P) Ltd., Publishers

[6] Carlos A. Estrada M. "New Technology Used in Gas Turbine Blade Materials "Scientia et TechnicaAnoXlll, No 36, September 2007.

[7] V. Ganesan "Gas Turbines " Tada McGraw-HiII Publishing Company Limited, 2003.

[8] Soon Kiat Yee, F.M. Hughes and J.Y. Milanovi6, Senior Member, IEEE "Comparative Analysis and Reconciliation of Gas Turbine Models for Stability Studies" University of Manchester, UK, 1-4244- 1298-6/07/$25.00 ©2007 IEEE

[9] A. Bagnasco, B. Delfino, G. B. Denegti and S. Massucco (Member, IEEE) "Management and Dynamic Performances of Combined Cycle Power Plants During Parallel and Islanding Operation "IEEE Transaction on Energy Conversion, Vol. 13, No, 2, June 1998.

[10] W. I. Rowen, "Simplified mathematical representations of heavy duty gas turbines", Transactions of the ASME. Journal of Engineering for Power, vol. \05, pp. 865-70, 1983.

[11] Philip Kiameh "Power Generation Handbook" Publisher: McGrawHillProfessional;© 2004 The McGraw-Hill Companies.

[12] Soon Kiat Yee, Jovica V. Milanovic, and F. Michael Hughes "Overview and Comparative Analysis of Gas Turbine Models for System Stability Studies" IEEE Transactions on Power Systems, VOL. 23, NO. I, February 2008

[13] P. Kundur" Power System Stability and Control" McGraw-Hill, Inc., 1994

[14] Sposor by Energy Development and Power Generation Committee of the IEEE Power Engineering Society "IEEE Recommended Practice for Excitation System Models for Power System Stability Studies "New York ,USA, IEEE, 2005.

[I5] A. Salehi, M.Eng.Sc.l , A.R. Seifi, Ph.D, and A.A. Safavi, Ph.D " Combined-Cycle Plant Simulation Toolbox for Power Plant Simulator" The Pacific Joumal of Science and Technology, Volume 9. Number I. May-June 2008 (Spring)