OCTOBER 2017 M.Sc. in Electrical and Electronics Engineering KAMERAN KAMAL SALMAN AL-DALWI

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MODELING AND SIMULATION OF BAZYAN GAS POWER PLANT

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KAMERAN KAMAL SALMAN AL-DALWI

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Modeling and Simulation of Bazyan Gas Power Plant

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Assist. Prof. Dr. A. Mete VURAL

By

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I hereby announce that all data in this research has been acquired and introduced as per scholarly tenets and moral lead. I additionally proclaim that, as wanted by this standard and manner, I actually have completely referred to and indicated all materialistic and outcomes that are not unique to the work.

Kameran Kamal Salman AL-DALWI

ABSTRACT

MODELING AND SIMULATION OF BAZYAN GAS POWER PLANT

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M.Sc. in Electrical and Electronics Engineering
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The aim of this thesis is to investigate the modeling and simulation of the Bazyan gas power plant (BGPP). The demand for energy in the developing regions of the world has shown a clear increase in the recent past. Therefore, it is important to use power generations that have high efficiency and specific power output, low pollutant emissions and low operating and maintenance costs for possible use of available fuels. Industrial gas turbines are one of the established technologies for power generation. Power supply systems require the exact models of energy system elements. Exciter, speed control and gas turbine are important components of the production units. First, each part of the turbine is described by its transfer function, and then the block model is thoroughly built. In addition to the turbine, the IEEE AC7B excitation system with an Power system stabilizer (PSS2B), a synchronous generator and a transformer are considered in simulation studies. This model is then adapted to the newly installed gas power plant BGPP in Iraq, using real data from the data sheets of the BGPP manufacturers. For the simulation, the station is connected to a load. Simulation studies are carried out under small signal disturbances, For example, a unit-step controller change, as well as large disturbing conditions such as ground fault and three phase faults. In each step, various system variables such as rotor angle, acceleration power, connection voltage and rotor speed are recorded and plotted.

Keywords: Gas turbine model; AC7B exciter; Power system stabilizer; Power System stability; Bazyan Gas Power Plant.

ÖZET

BAZYAN DOĞAL GAZ GÜÇ SANTRALİNİN MODELLEMESİ VE BENZETİMİ

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Tez Yöneticisi: Y. Doç. Dr. Ahmet Mete VURAL
Ekim 2017
92 sayfa

Bu tezin amacı Bazyan Doğal Gaz Güç Santralinin (BGPP) modellemesini ve benzetim çalışmasını yapmaktır. Dünyanın gelişen bölgelerindeki enerji talebi son yıllarda belirgin bir artış göstermiştir. Bundan dolayı, yüksek verim, belirgin güç çıkışı, düşük çevre kirlilik emisyonu ve mevcut yakıtların muhtemel kullanımları için düşük işletme ve bakım maliyetlerine sahip güç üretim santrallerini kullanmak önemlidir. Endüstriyel gaz tribünleri güç üretimi için kurulu teknolojilerden bir tanesidir. Güç tedarik sistemleri enerji system elemanlarının kesin modellerine ihtiyaç duyar. Uyarıcı, hız control ve gaz tribünü üretim ünitelerinin önemli bileşenleridir. İlk olarak tribünün her bir parçası bir transfer fonksiyonu ile tanımlanmış ve daha sonra ise blok model oluşturulmuştur. Tribüne ek olarak, güç sistemi dengeleyicisi (PSS2B)'ne sahip IEEE AC7B tipi uyartım sistemi, senkron jeneratör ve bir transformatör benzetim çalışmalarında dikkate alınmıştır. Bu model daha sonra BGPP üreticilerinin veri listelerinden alınmış gerçek veriler kullanılarak Irakta yeni inşa edilmiş BGPP'ye uyarlanmıştır. Benzetim için istasyon bir yüke bağlanmıştır. Benzetim çalışmaları küçük sinyal bozucuları altında uygulanmıştır. Örneğin, birim-adım denetleyici değişikliği ve bununla birlikte toprak arızası ve üç-faz arıza gibi büyük bozucu şartlar. Her adımda rotor açısı, ivmelenen güç, bağlantı gerilimi ve rotor hızı gibi farklı sistem değişkenleri kaydedilmiş ve çizilmiştir.

Anahtar Kelimeler: Gaz tribünü; AC7B uyartıcı sistemi; PSS2B Güç Sistemi Dengeleyicisi, Bazyan Doğal Gaz Güç Santrali.

To My dear mother, father, my wife and children

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LIST OF SYMBOLS/ABBREVIATIONS

AVR	Automatic Voltage Regulator
HDGT	Heavy Duty Gas Turbine
IEEE	Institute of Electrical and Electronics Engineers
IGV	Inlet Guide Vanes
BGPP	Bazyan Gas Power Plant
LVS	Low Value Select
PID	Proportional-Integral-Derivative
PSS	Power System Stabilizer
T_1	Temperature at the inlet compressor
T_2	Temperature at the outlet compressor
T_3	Temperature at the inlet turbine
T_4	Temperature at the outlet turbine
P_b	Pressure at the inlet compressor
P_a	Pressure at the inlet compressor
γ	Specific heat ratio
w_t	Turbine work
w_c	Compressor work
q_h	Heat supplied to the cycle
η_{cy}	The cycle thermal efficiency
C_p	Specific heat constant
W_f	Fuel flow
K_2	Combustor's temperature raise coefficient
T_f	Temperature at the inlet of the gas turbine

η_t	Turbine efficiency
T_e	Gas turbine exhaust temperature
P_{mg}	Turbine’s mechanical output
P_c	Compressor consumes power
K_0	The output factor of the gas turbine
P_g	The net output of the gas turbine
P_{mec}	Mechanical power
T_R	The reference temperature
N, W_m	Rotor speed
W_F	Fuel flow
T_{mec}	Mechanical torque
δ	Rotor angle
V_T	Terminal voltage
P_{acc}	Acceleration power
T_R	Terminal voltage transducer
X_C	Terminal voltage transducer
R_C	Terminal voltage transducer
K_c	Rectifier Commutation Factor
K_D	Load Factor
K_{DR}	AVR Derivative Gain
K_E	Alternator Gain
K_{F1}	Field Voltage Feedback Gain
K_{F2}	Field Current Feedback Gain
K_{F3}	Rate Feedback Gain
K_{1A}	FVR Integral Gain
K_{IR}	AVR Integral Gain
K_L	Lower Forcing Limit

K_P	Potential Forcing Term
K_{PA}	FVR Proportional Gain
K_{PR}	AVR Proportional Gain
T_{DR}	AVR Derivative Gain Filter
T_E	Exciter Time Constant
T_F	Rate Feedback Time Constant (Not used)
V_{Amax}	FVR Positive Limit
V_{Amin}	FVR Negative Limit
$V_{Emax-E1}$	Maximum exciter EFD, pu
$V_{E0.75max-E2}$	75% Maximum exciter EFD, pu
$S_{Emax-SE1}$	Saturation Factor at Maximum EFD
$S_{E0.75max-SE2}$	Saturation Factor at 75% Maximum EFD
V_{Emin}	Exciter Field Current Lower Limit
V_{Emax}	Exciter Field Current Upper Limit
V_{Rmax}	AVR Positive Limit
V_{Rmin}	AVR Negative Limit
$S_{Emax-SE1}$	Saturation Factor at Maximum EFD
$S_{E0.75max-SE2}$	Saturation Factor at 75% Maximum EFD
V_{Emin}	Exciter Field Current Lower Limit
V_{Emax}	Exciter Field Current Upper Limit
V_{Rmax}	AVR Positive Limit
V_{Rmin}	AVR Negative Limit
$S_{Emax-SE1}$	Saturation Factor at Maximum EFD
$S_{E0.75max-SE2}$	Saturation Factor at 75% Maximum EFD
V_{Emin}	Exciter Field Current Lower Limit
V_{FEmax}	Exciter Field Current Upper Limit
V_{Rmax}	AVR Positive Limit
V_{Rmin}	AVR Negative Limit

$S_{Emax-SE1}$	Saturation Factor at Maximum EFD
$S_{E0.75max-SE2}$	Saturation Factor at 75% Maximum EFD
V_{Emin}	Exciter Field Current Lower Limit
V_{Emax}	Exciter Field Current Upper Limit
V_{Rmax}	AVR Positive Limit
T_1	Inertia = 2*H
W	Gain = 1/ droop (pu MW / pu speed)
X	Speed Control lead time constant (s)
Y	Speed Control lag time constant (s)
Z	Speed Control mode (1=droop, 0=isochronous)
MAXIMM	Request upper limit (pu)
MINIMUM	Request lower limit (pu)
a	Valve positioner
b	Valve positioner time constant
EFD	Exciter output voltage
f_1	TX=TR-700*(1-WF)+550*(1-N)
f_2	1.3*(WF-0.23)+0.5*(1-N)
T_r	Reference Temperature rate (°F)
T_R	Rated exhaust temperature (°F)

C	Valve positioner
K_f	Fuel feedback system
E_{CR}	Combustion time delay (s)
E_{TD}	Turbine and exhaust delay time (s)
T_{CD}	Compressor discharge time constant (s)
IFD	Synchronous machine field current
HRSG	Heat Recovery Steam Generator

CHAPTER 1

INTRODUCTION

1.1 General Information

Developing nations find it extremely difficult to handle power scarcity problems involving huge gap between supply and demand. Distributed generation provides lots of scope and solution for this problem. Solar, wind and bio mass are the various sources of distributed generation with environmental friendly approach. Bio mass gasification plants generate syngas that can be used as an alternative fuel for diesel or natural gas. Syngas combusted in gas turbine provides mechanical energy to the electrical generators [1].

Gas turbines afford transient operations due to starting, increment and decline of loads, Moreover sudden shutdowns may lead to unstable system over a period of time. For better understanding the turbine dynamics, these transitory circumstances must be examined. Along these lines, numerical of these convoluted systems must be inferred which imitates the turbine system running over a scope of different working conditions. Gas turbines are an important piece of world manufacture, by giving mechanical power for carriage, control era, and assembling plants. The developing need for dependable power has incited the design of stationary gas turbines which work on different fuels for example, diesel, normal gas, synthetic coal gas, and others [2].

To preferable watch and control such these compound machines; an entire dismemberment for expectation of the transient working is requested with running with numerical depiction. Gas turbines encounter operations because of new businesses, variable burdens, and sudden shutdowns which may prompt system withdrawal over a timeframe. To preferable know the turbine dynamic behavior; these transient cases have to be analyzed [2].

The developments of the modeling offered in this thesis is a piece of system gone for the prelude of on-line demonstrative and prognostication capacities to the steady gas turbine technique that will give expanded unwavering quality, security, and productivity in gas turbines. Every sub-system for gas turbine plant is presented independently including the compressor, burning chamber, turbine, fuel input, and the electrical power generator. Intake air is compacted in the compressor and is then gone through the recover where it gains heat from the turbine exhaust gases [2].

Model-instituted diagnostic procedure eliminates the need for excrescent hardware during the use of analytically estimated plant output for comparison. In creating a mathematical model and diagnostic planning which can successfully detect and alert system executive that a problem exists, the need for plant or system maintenance can be reduced while increasing total safety [2].

A decent origination for gas turbine and its working can be separated into three noteworthy segments [3],

1. Compressor,
2. Combustion chamber,
3. Turbine.

Of the three, two of them are described as rotating machines and the rest one is a heat addition device. A schematic of a typical heavy duty gas turbine (HDGT) with their elements are shown in Figure 1.1 [4].

The gas turbine gains its power by the use of energy of ignite gases and air, which is at high temperature and squeeze by spread through the various ring of stator and rotor blades. To get a high pressure of running fluid, which is fundamental for expansion, a compressor is needed. The amount of the working fluid and speed requirement are generally more, so, mostly, a centrifugal or an axial compressor is utilized. The turbines push the compressor and then it is connected to the turbine shaft. Therefore, gas turbine is departed to the compressor, the combustion chamber, and the turbine [5].

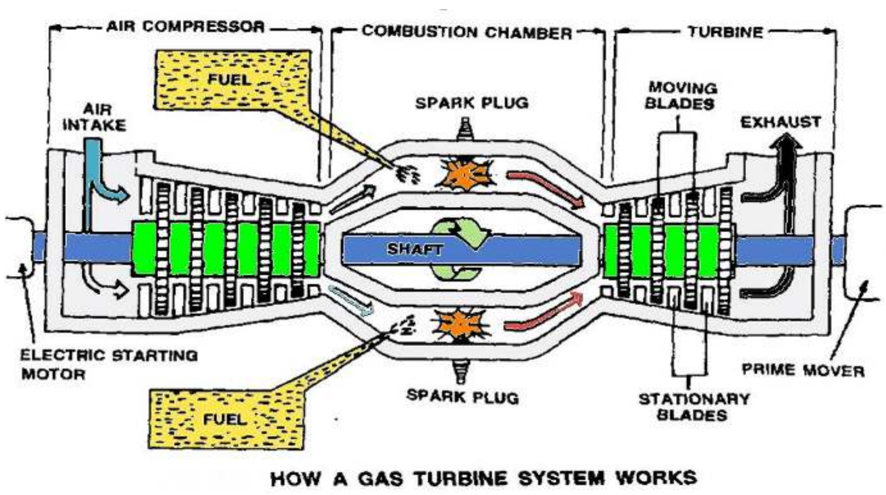

Figure1.1 A schematic perspective of a commonplace HDGT and its significant parts [4]

Through gas turbine running, air is taken from the ambience and is absorbed by the first line of compressor blades. From there, the running fluid attains mechanical power from the compressor and gives rise to that pressure and temperature increase quickly. Meanwhile, the air contain appropriate requirement to be conveyed into the burning room, which is the component in charge of blending the arrived air with fuel, making ignition and creating high temperature vent gasses. While pipe gasses have been produced from the ignition chamber, they are pushed to the turbine, which is the component in charge of removing vitality from the gasses in make out of mechanical rotatory power, which is utilized to push the compressor, and creating additional energy to turn apparatus or producing push [6]. The rotating machines are for the most part are called turbo machines [7].

The control arrangement of the gas turbine has three sub control arranges

a) The speed control system,

b) Temperature control system,

c) Acceleration control system.

The simplified version of a solitary shaft gas-turbine with its control is illustrated in Figure 1.2 [8].

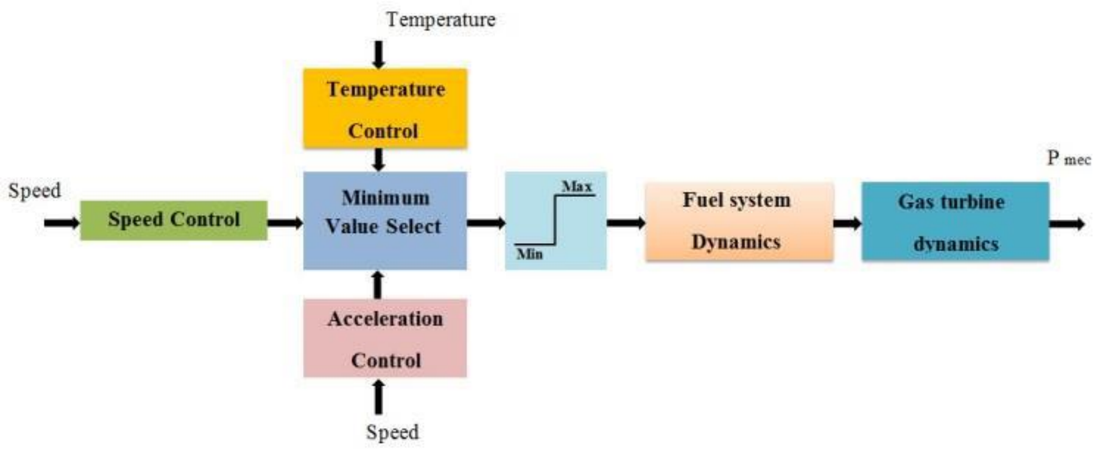

Figure1.2 Simplified version of a solitary shaft gas turbine with control [8]

It is one of the most important control schemes under normal operating conditions, including its control (fuel requirement) with a temperature control system and an acceleration control. These three unique controllers' yields are contributions to a smaller exit that selects the smallest sum from the fuel for three needs. The needed fuel is sent to gas turbine system [9].

The temperature control is demanded if there should arise an occurrence of abnormal working conditions. Exhaust temperature is measured by an arrangement of thermocouple consolidation radiation shields [10],

The acceleration speed control system is dynamic in the circumstance of unusual working conditions. The feedback signal in this control configuration is utilized for two purposes:

1. For enhancing the damping about the speed control system by producing a secondary stabilizer term,
2. For protecting from over speed upon a load refusal [10].

The principle capacity of this exciter system is to deliver direct current (DC) to the synchronous generator field winding. Moreover, the exciter system executes control and defensive fundamental capacities with a specific end goal to get ideal system execution by regulating the field-voltage and field-current. The exciter system must be equipped for answering transient flow with field driving with the generator moment here and the aspect of short-term.

Point view of energy of the system, it is important to have the exciter system which must be available inside reinforcement of system stability in addition to voltage domination. Also, here it has to response rapidly to their obstacles in order to make transient stability does very well. Moreover, it should be capable of modifying the generator field so as to improve small signal stability [11].

Exciter system includes an inner feedback which regulates generator field voltage or exciter current, an exciter current limiter, VFEMAX (Exciter Field Current Upper Limit), to conserve the field of the generator, and the proportional integral derivative (PID) based automatic voltage regulator (AVR) [12].

Power system stabilizer (PSS) gives further information which is singular towards the exciter system in order to improve the damping of the power system in the domination of exciter. Accelerating power, frequency and rotor speed deviation can be input signals for stabilizing. The power system signals control the exciter system in addition to the improvement of power system dynamics [11].

1.2 Outline of Thesis

This thesis is organized as six chapters .They are given as follows:

Chapter 1: This chapter provides a simple detail towards this work and overview about the study which includes the contribution of the thesis and the organization of the project.

Chapter 2: This chapter explains where the research in the literature and gives extra recent literature report.

Chapter3: This chapter explains the theoretical background of the gas turbine with its major components and operation, also explains the control system of the gas turbine with block transfer functions.

Chapter4: This chapter explains the modeling of the Bazyan Gas Power Plant. This includes the modeling of all parts of Bazyan gas turbine and Bazyan exciter system and also shows the PSS model of Bazyan Gas Power Plant.

Chapter 5: This chapter presents the simulations and the related discussion.

Chapter 6: This chapter presents the conclusion and the future work which can be possible done in the future.

CHAPTER 2

LITERATURE SURVEY

2.1 Introduction

The relevant research reports in the literature with regard to the field of designing and simulation of Bazyan Gas Power Plant are briefly cited below.

2.2 Related This Work with the Other Literature

Inventors Franz Stolze of Berlin had patents for outlines which included these parts (compressor, combustor and turbine) as ahead of schedule as 1873. Designs for machines looking like the present day gas turbine, containing a compressor, combustor and turbine, have existed for over a hundred years [13].

The earliest patent on gas turbine was that of the Englishman, John Barber, in 1879 [7].

Two French engineers, Armengaud and Lemale (1904), assembled a unity that did a little more than turn itself over. The compressor productivity was most likely close to 60 percent and the greatest gas temperature which could be utilized was around 740 K [14]. This machine, designed by Armengaud and Lemale in France, was barely up to the job since it struggled to drive its own 25 stage compressor. Not surprisingly, their design failed to catch on [13].

It had actually lower efficiencies and bad turbine accessories which actualized the disappointment of various early endeavors to develop a gas turbine motor [14].

Nonetheless, a commonsense gas turbine equipped for generating any useful power was not built until 1909. Brown Boveri (1939), installed the first industrial gas turbine in commercial service in Neuchatel, Switzerland. The prior years World War II actualized the significant specialized advances that numerous designers had been attempting to accomplish.

This was not in the field of modern gas turbines, but rather in a fundamentally the same as innovation, the aircraft jet engine. Intensive government funded programmes were initiated in the UK and Germany as the two sides battled for superiority. Since the aircraft piston engines of the 1930s were reaching their technological limits, the first country to fit jet engines to their fighter aircraft would have a huge advantage in speed and power [13].

Although several fairly successful attempts were made in Germany during the period 1908-1930 to construct gas turbines [14], the race was won by the Germans when Von Ohain's jet powered the first aircraft of its type in 1939. This was closely followed by the first flight using the Whittle engine in the UK in 1941[13].

This wartime advancement prompted the principal actual contribution of a large portion of the present makers of extensive modern gas turbines. The company that manufactured the first jet engines in the UK and many of its employees had since become part of GEC's (General Electric Company) gas turbine activities. GE (General Electric) of the USA was given a Whittle engine to clone and manufacture in the USA, starting in 1941. Many physical features of the Whittle engine such as the 'combustion cans' found an echo in current GE industrial designs, the first of which was built in 1948. Meanwhile, Westinghouse was awarded a contract by the US Navy in late 1941 to design and build a completely new jet engine design. The programme gave rise to its first test flight in 1943 and its continuation led to Westinghouse's first industrial gas turbine in 1949[13].

The gas turbine was used as a power enhancer rather than a prime source of generation. During the period of the mid 1960s,the manufacturers of gas turbines were struggling to sell enough units despite the fact that it was possible to use them to power railway locomotives, ships and even tanks as well as electric generators[13].

The mid 1960s brought a significant breakthrough for the makers of gas turbines. Blackouts in the electricity systems of the UK and North America prompted the establishment of a substantial number of units for use in future emergencies. The ability of gas turbine to start up very quickly was a crucial factor in the decision to use it for this application[13].

The new generation of machines that followed in the early 1970s was a lot larger, with unit sizes up towards 100MW, and more efficient. A lot of these running together meant that if one failed it wasn't a major problem. Now, things are starting to change as unit sizes increase[13].

At approximately the same time, in 1973, the newly emerging gas turbine boom was strangled by the decision of the OPEC nations to quadruple the price of oil almost instantaneously. Harder times set in as oil and gas came to be viewed as too precious for use in power generation. This difficult period lasted until the mid-l980s, though most of the major companies managed to keep their operations going by virtue of their sheer size and diversity[13].

Despite the fact that some of these plants in developing countries suffered from poor performance, the gas turbine boom had been restarted. In Europe, interest was patchy until the privatisation of the UK gas and electricity industry triggered the 'Dash for Gas'. Further encouragement was given by new environmental regulations and, to a lesser extent, the lifting of a 1975 EC directive restricting the use of gas for power generation. Of the main European equipment suppliers, ABB (formed in 1988 from the merger of ASEA and Brown Boveri) and Siemens had already begun to establish themselves as international suppliers of combine cycle gas turbines during the 1980s [13].

Here , W. I. Rowen (1983) gave a paradigm of the sort of a gas-turbine which is utilized because of effective execution investigations of the energetic system. The model of Rowen comprises of an arrangement of mathematical conditions portraying the unfaltering state qualities of turbine thermodynamics which is the gas, direct the time late, and a couple of applicable dominations containing the temperature domination, governor, and acceleration control. The model of Rowen has given a beginning stage to improvement of different models and the one in this essay [8].

The loyalty of the Rowen's model (1993) was affirmed by genuine estimations by Hannett and Khan [15].

Under the IEEE System Dynamic Performance Subcommittee, The Working Group on Prime Mover and Energy Supply Models for System Dynamic Performance Studies (1994), has their vital goals the improvement of primary of mover/vitality provide many aspects in using for energetic system reproduction programme. That essay contains displaying data on gas-turbine and steam-turbine joined cycles which are getting to be noticeably expanding supporters of the force to be reckoned with's era. The reaction attributes of this era design vary significantly from those of ordinary steam cycles and should be comprehended and demonstrated effectively to decide the dynamic communication of the prime movers with the matrix transmission qualities [16].

Q, Zhangand and P.L.So (2000) proposed a dynamic model for combined cycle plant that incorporates a gas turbine, heat recovery, steam generator and steam turbine and includes speed control, temperature control and inlet guide vane control.The proposed model and its controls are tested on a simple two-area power system [17].

L.M.Hajagos and G.R.Berube (2001) represented the suitable block diagram for demonstrating the governor and simple-cycle gas turbine with testing and experience [18].

There are many as, A. Kurita, A.Kunitomi , H. Okamoto, P.Pourbeik W.W.Price S.Ihara and Y. Tada (2001), addressed the repeated dependency from the turbine of the gas power output and gives a physical-based aspect from gas turbine which might make the ability of parameter estimation of the frequency dependency from the temperature dependency which is circled [19].

Naoto Kakimoto, and Kazuhiro Baba (2003) represented the simulation of combine cycle plant to see how the combined cycle (gas with steam turbine) acts while that fell ,namely, system frequency. To study dynamic behavior of combined cycle plants is important. The combined cycle plant of several dynamic aspect is given before. In this case, they made modles like a single-shaft combined cycle plant. To see how the combined cycle acts is they execute numerical simulations when the system frequency fell. [20].

P. Centeno, I. Egido, C. Domingo, F. Fernández, L. Rouco and M. González (2005) reviewed the dynamic model of gas turbine for power system stability studies. It portrays the principle control loops and clarifies the reasons for every one and additionally unique approaches to execute them [21].

Soon Kiat Yee, F.M. Hughes and J.V. Milanović (2007) represented a comparative analysis of two most widely used mathematical models, namely the IEEE and Rowen’s model [22].

Soon Kiat Yee, Jovica V. Milanovic, and F. Michael Hughes (2008) shown a similar examination and a review of different models of gas turbines distributed in various literature. This paper presents a comparative analysis and an overview of various models of gas turbines published in different literature [23].

Zhitao Wang and Shuying Li (2009), present Simulation Study on Fuzzy PID control of gas turbine generating sets speed[24].

Homam Nikpey, Mohsen Assadi and Peter Breuhaus (2012), they are development of an artificial neural network model for combined heat and power micro gas turbines[25].

Amit S. Karande and M.J. Nigam (2015) working on design of a fuzzy PID controller for a gas turbine power plant which is the reason that works like an obstacle in the system of transmission and distribution. The design of Fuzzy PID is beacuase of the reason which is for MontazerGhaem power plant gas turbine(GE900IE. The known aspect (linear) is correlated inside fuel flow the reason is because of controlling rotor speed of turbine during startup and power demand variation , all this is While designing [26].

Yusen Li, Liying Cao and Ye Wang (2015), presented the design of gas turbine flow meter based on the technology of automatic gain contro [27].

S. Balamurugan , N. Janarthanan, K.R.M. Vijaya Chandrakala (2016), they was studies on Small and large signal modeling of heavy duty gas turbine plant for load frequency control [28].

As it is shown in the above survey, the development of gas turbine model is continuing year after year to build a good performance when use as an electrical power generation.

2.3 The Present Work In The Literature

The present work models Bazyan Gas Power Plant and simulates it to study dynamic and transient stability. Firstly, transfer functions are explained. The model is built thoroughly by transfer functions; excitation system is of IEEE AC7B type with power system stabilizer (PSS2B). In addition to these, a turbine, a synchronous generator and a transformer are considered in the simulations. The power station is connected to a load. Simulation studies are performed under small signal disturbance such as a step change in governor input, as well as large disturbance conditions such as line-to-ground and three-phase faults. At each step, various system variables such as rotor angle, acceleration power, terminal voltage and rotor speed are obtained and plotted.

CHAPTER 3

THEORETICAL BACKGROUND OF GAS POWER PLANT

3.1 Introduction

According to the statement of World Energy in 2004, the energy increase is continuously occurred about double over the next 20 years. Heavy duty gas turbine (HDGT) is one of the great built up advancements for electric generation [29].

Gas turbines manage the transient operations because of the starting, increasing/decreasing loads, and sudden shutdowns that may stimulate hazardous conditions over a time frame. To better comprehend the turbine progression, these transiently circumstances must be investigated. Accordingly, the mathematical models of these complicated systems must be derived and determined over a wide range of operating conditions. Gas turbines are a necessary part of the global economy by giving mechanical power to the synchronous generators. The evolving need for reliable performance has stimulated the design of stationary gas turbines operating with various fuels, such as diesel, normal gas, synthetic carbon gas, and others [2].

To have better understanding of these complicated systems, a whole examination is required for the predicting the steady-state and transient working conditions operating under different loading conditions. Gas turbines encounter operations because of startups, variable loads, and surprising shut-down that may incite system retraction over a timeframe. To know the dynamic behavior of the turbine better these transient cases must be analyzed in detail [2].

The developed model offered in this work is part of the strategy aimed at predicting online diagnostic and predictive capabilities for the stationary gas turbine process, resulting in increased reliability, safety and efficiency in gas turbines [2].

Every subsystem of the gas turbine plant was modeled separately including the compressor, combustion chamber, turbine, fuel input, and the electrical power generator. Inlet air is compressed in the compressor and is then passed through the recover where it gains heat from the turbine exhaust gases [2].

During gas turbine operation, air is taken from the atmosphere and is sucked by the first row of compressor blades. From there, the working fluid receives mechanical power from the compressor causing that pressure and temperature increase rapidly. In that specific minute, air has appropriate conditions to be sent to the burning chamber; part in charge of blending the approaching air with fuel, making ignition and delivering high-temperature-pipe gasses. At the point when pipe gasses have been discharged from the ignition chamber, they are headed to the turbine columns; parts in charge of extricating vitality from the gasses in type of mechanical-rotational-control, which is utilized to drive the compressor and delivering additional energy to drive apparatus or creating thrust [6]. Therefore, the rotating machines are commonly referred to as turbo machines [7]. Later on, vent gasses are freed to the air through the exit nozzle [6]. Here it can be noticed that gas of turbines has designed by considering oil and natural gas [5].

Model-based diagnostic method eliminates the need for exquisite hardware during the use of analytically valued plant services for comparison. In making a numerical model and analytic arranging which can effectively distinguish and ready system official that an issue is out there, the need for plant or system maintenance can be reduced as the overall safety is increased [2].

3.2 A Brief Review of Power Generation Thermodynamics

The gas turbine power stations used in the electricity industry are divided into two groups according to the operating cycle [5]:

a. Open-cycle working gas turbine

b. Closed-cycle working gas turbine

3.2.1 Open Cycle Gas Turbine

Gas turbine systems operate on the thermodynamic cycle known as the Brayton cycle [7]. The Brayton circuit regulates the behavior of gas turbines [10].

In order to analyze the gas turbine system in a suitable form, the following assumptions are often used [30].

1. The working substance is treated as the air of fixed composition. The air is a perfect gas and has a constant specific heat.
2. The combustion procedure is substituted by a heat exchange prepared from an outside source. In another words, the mass stream rate stays unchanged all through the system.
3. The entry gateway and fumes procedure are supplanted by a consistent pressure process that will thusly entire the gas turbine cycle.
4. All processes are internally reversible.

It shows in a cycle what happens to air when it goes out of the gas turbine and inside it . The normal cycle depicts the relation between the space taken from air (called volume, V) and p is under. The Brayton cycle, appeared in actualistic shape in Figure 3.1 as a pressure-volume outline, is an epitome of the properties of a stationary measure of air as it goes during a gas turbine in working. These same focuses are likewise appeared in the motor schematic in Figure 3.2 [3].

The Brayton cycle is completed in Figure 3.1 by an operation that reduces the amount of air (temperature decrease) when heat is released to the air.

A gas turbine designed and operated to neatly follow the Brayton cycle is as a simple circular gas turbine [3].

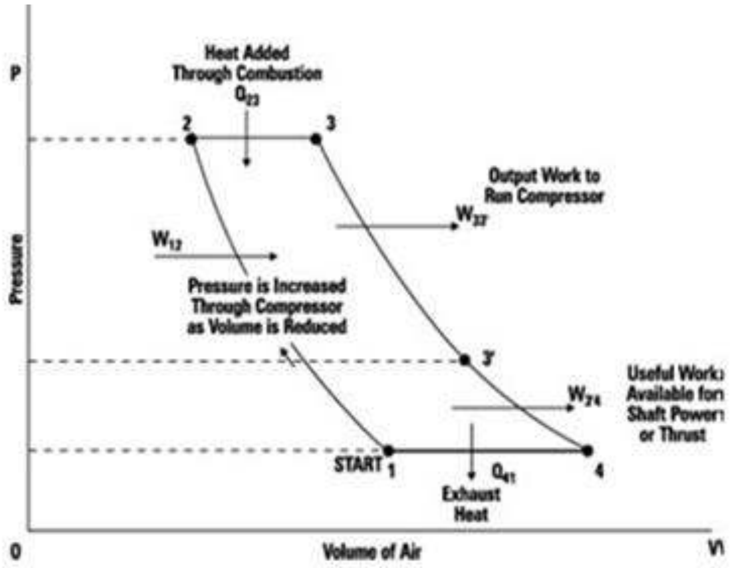

Figure3.1 Brayton Cycle pressure-volume graph for a unity mass of active liquid, indicating work (W) and heat (Q) inputs and outputs [3].

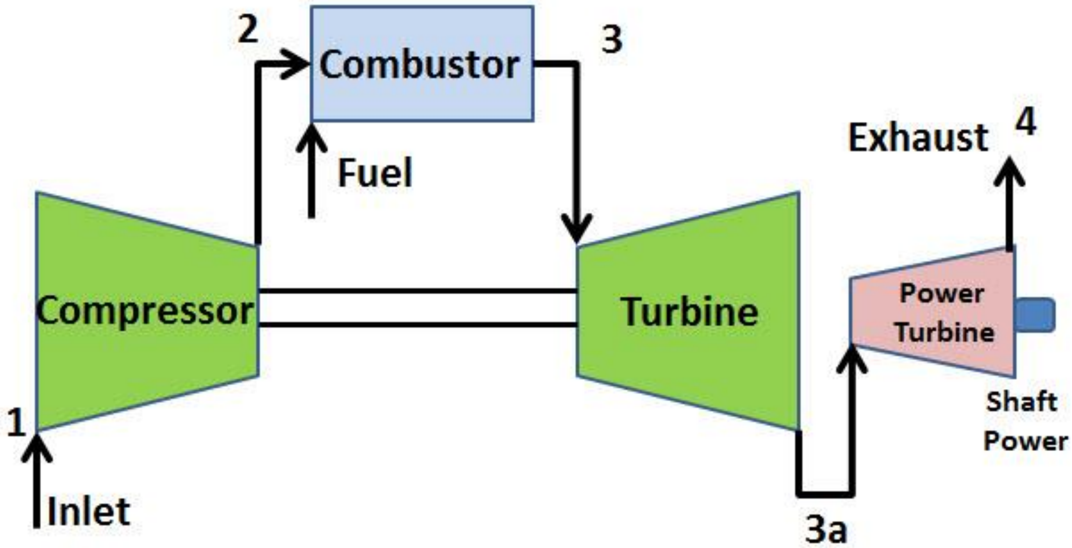

Figure3.2 Gas turbine graphic showing relative focuses from the Brayton Cycle outlines [3].

The air is compressed from point 1 to point 2. This increases the pressure when the volume of the air is reduced. The air is then heated at constant pressure from 2 to 3 in Figure 3.1. This heat is added by injecting the fuel into the combustion chamber and is ignited on a continuous basis. The hot-pressed air at point 3 can expand (from point 3 to 4), thereby reducing the pressure and temperature and increasing the volume. The engine in Figure 3.2 represents the flow through the turbine to point 3 and then flows to the point 4 during the propulsion turbine to turn an axis or a ship propeller. In Figure (3.1), the flow is from point 3 to 4 during the discharge nozzle to produce thrust. The advantageous work in Figure (3.1) is specified by curve 3-4. This is the energy available to justify the output wave power for a land-based gas turbine, or the thrust for a jet aircraft [3].

Figure 3.3 shows an ideal Brayton cycle. It is usually alluded to as the Brayton Cycle after George Brayton. It has two adiabatic-reversible (isentropic) procedures and two isobaric (consistent pressure) forms [32].

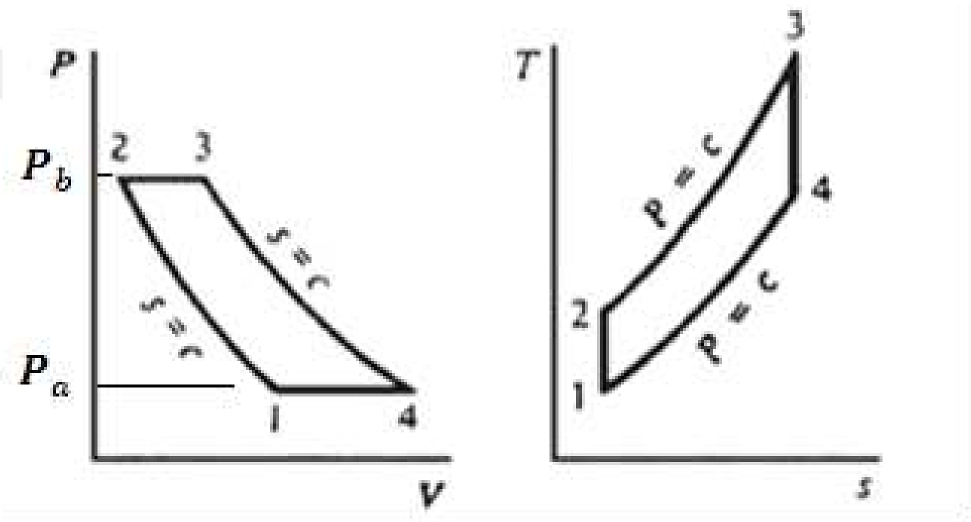

Figure3.3 P-V and T-S chart of a perfect Brayton Cycle [32].

To evaluate the cycle thermal efficiency, the best way is first to calculate the temperatures at the various cycle locations. For the isentropic processes 1-2 and 3-4, we have [30]

$$\frac{T_2}{T_1} = \frac{T_3}{T_4} = \left(\frac{P_b}{P_a}\right)^{\frac{\gamma-1}{\gamma}} \qquad (3.1)$$

Where

T_1= temperature at the inlet compressor, T_2= temperature at the outlet compressor

T_3= temperature at the inlet turbine, T_4 = temperature at the outlet turbine

P_b= pressure at the output compressor, P_a = pressure at the inlet compressor

γ = specific heat ratio

The cycle thermal efficiency, based on a unity of air passing during the system, is

$$\eta_{cy} = \frac{w_t - w_c}{q_h} \tag{3.2}$$

where

w_t = work produced by turbine

w_c = work produced by compressor

q_h= heat supplied to the cycle

Applying the first-law equation to the compressor, the combustor and the turbine, we can change (3. 2) to [30]

$$\eta_{cy} = \frac{C_p(T_3 - T_4) - C_p(T_2 - T_1)}{C_p(T_3 - T_2)} = 1 - \frac{T_4 - T_1}{T_3 - T_2} \tag{3.3}$$

where C_p is the constant specific heat.

This sort of cycle is chiefly utilized as a part of larger part of gas turbine control plants as it has numerous innate focal points, such as, [5]:

1. The gas turbine will be enlivened from cold start to entire load without heat-up time.
2. Low weighting and size.
3. Fuels. Any hydrocarbon fuel from high octane -gas to extraordinary diesel oils can be utilized in the burning chamber.
4. The status of a prompt begins and take-up of load regularly focuses in support of open-cycle station when the station is utilized as peak station plant.
5. The power to weight ratio is large as compared to closed cycle, therefore it is economical for moving vehicles and aircraft [33].

3.2.2 Closed Cycle Gas Turbine

The ideal cycle of a simple-steam power station is a modification of the Carnot cycle proposed by Professor William John Macquorn Rankine. The ideal cycle was later named as the Rankine cycle [5].

It is clear that the working liquid (air or some other appropriate gas) turning out from compressor which is warmed in a warmer by an outside source at consistent weight when it is in not opened cycle gas turbine plant. High temperature and pressure air turning out from the outside warmer is transferred inside the gas of the turbine. The liquid turning out from the turbine is cooled to its unique temperature in the cooler utilizing outer cooling source before going to it namely, compressor. The working liquid is persistently utilized as a part of the program except for the change of stage and the needed heat to the working liquid in the heat exchanger is given [5].

The processes that comprise the cycle are shown in Figure 3.4 which is explained in four points [30].

1. Constant pressure prepare warm expansion in the boiler (1-2).
2. Reversible and adiabatic developmental approaches in the turbine (2-3).
3. Consistent pressure and warm dismissal are prepared in the condenser (3-4).
4. Reversible and adiabatic pressures handle in the pump (4-1).

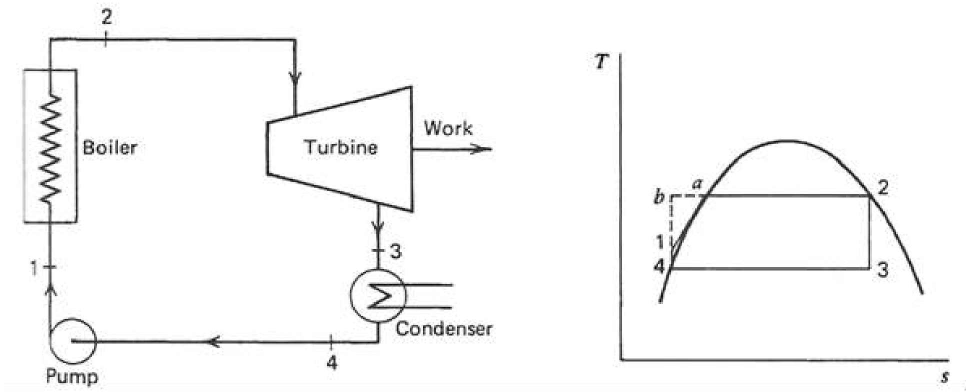

Figure3.4 Simple steam power station working on the Rinkine cycle [30]

The advantage of the closed cycle gas turbine plants can be summarized as:

1. The inherent drawback of an open circuit gas turbine is the atmospheric backpressure at the turbine exhaust. In the case of closed loop gas turbine plants, the backpressure can be increased. Therefore, the machine can be smaller and less expensive than the machine used to develop the same power using an open circuit system.

2. The closed circuit avoids erosion of the turbine blades due to the contaminated gases and contamination of the compressor vanes by dust.

3. The filtration of the incoming air is completely eliminated.

4. The speed ratio in the compressor and in the turbine is independent of the load and the thermal efficiency of the full load, covering the entire range of the operating loads.

5. The repair cost is small and dependability is high because of longer helpful life [5].

However, despite the above great advantages, there are some drawbacks of this turbine, such as:

1. The system is reliant on outer means as extensive amount of cooling water which is required in the pre-cooler.

2. Higher internal pressures require a complicated construction of all components, and a high quality material is required which increases the cost of the system.

3. The response to load fluctuations is poor compared to the open-cycle system.

4. It requires very large heat exchangers, since the heating of the working fluid takes place indirectly [5].

5. Large amount of cooling water is needed in the radiator [33].

3.3 Gas Turbine Architecture

More prominent comprehension of the gas turbine and its operation can be picked up by considering the following three parts [3], (Figure 3.5)**:**

1. The compressor,
2. The combustion chamber, and
3. The turbine.

Of the three, two are rotating machines and the third one is a heat addition device [34].

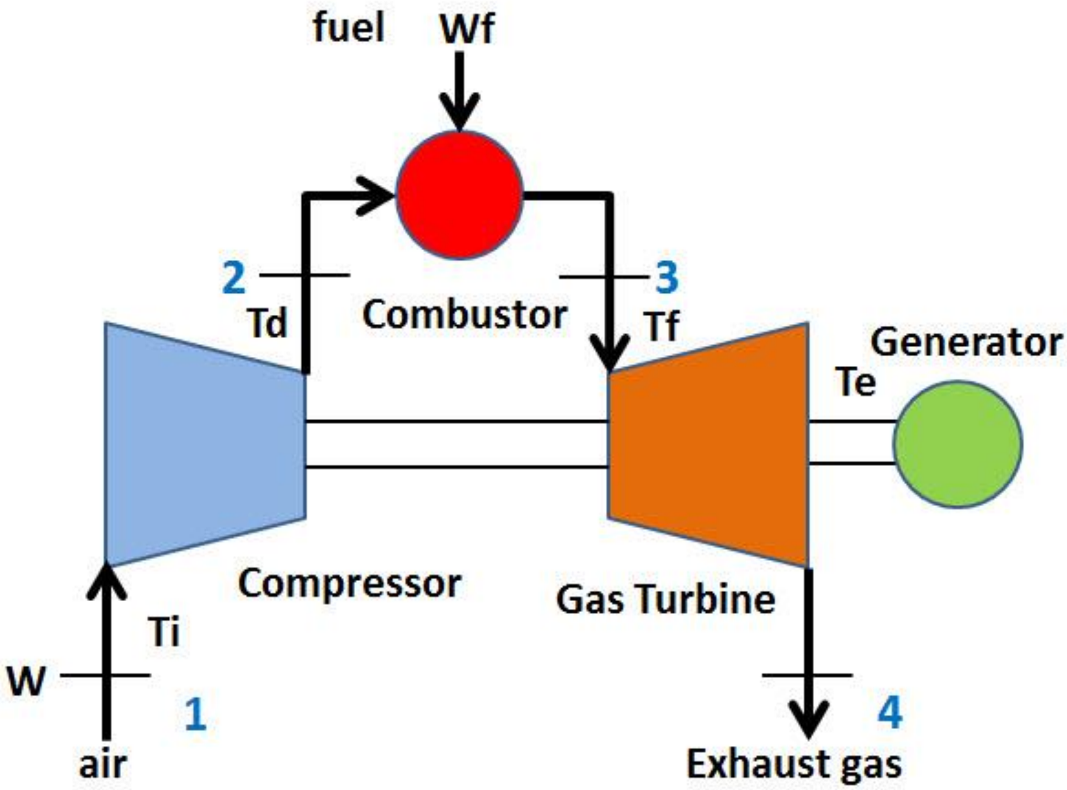

Figure3.5 A schematic picture of a gas turbine showing temperature point [34]

3.3.1. The Compressor

A compressor is a gadget, that pressurizes an active liquid [32] .The high stream rates of turbines and generally direct pressure proportions which require the utilization of revolving compressors [5].

The compressor segments are associated with the turbine by a shaft in order to enable the turbine to turn the compressor along the lines expanding the pressure [3]. With air flow inside the processor viewed as an adiabatic change, the compressor temperature at the compressor output can be expressed as follows [19]:

The types of compressors, which are generally utilized, are of two sorts, axial flow and centrifugal sorts [5]. Little gas turbines utilize centrifugal compressors while all the bigger ones utilize axial compressors [10].

3.3.1.1 Axial-Flow Compressor

The axial flow compressor consists of a series of rotor and stator stages with decreasing diameters along the airflow, as shown in Figure (3. 6). The blades are attached to the rotor and the rotors are attached to the shaft. The stator vanes are attached to the stator housing. The stator vanes lead the air stream to the next rotor stage from the previous rotor stage [5].

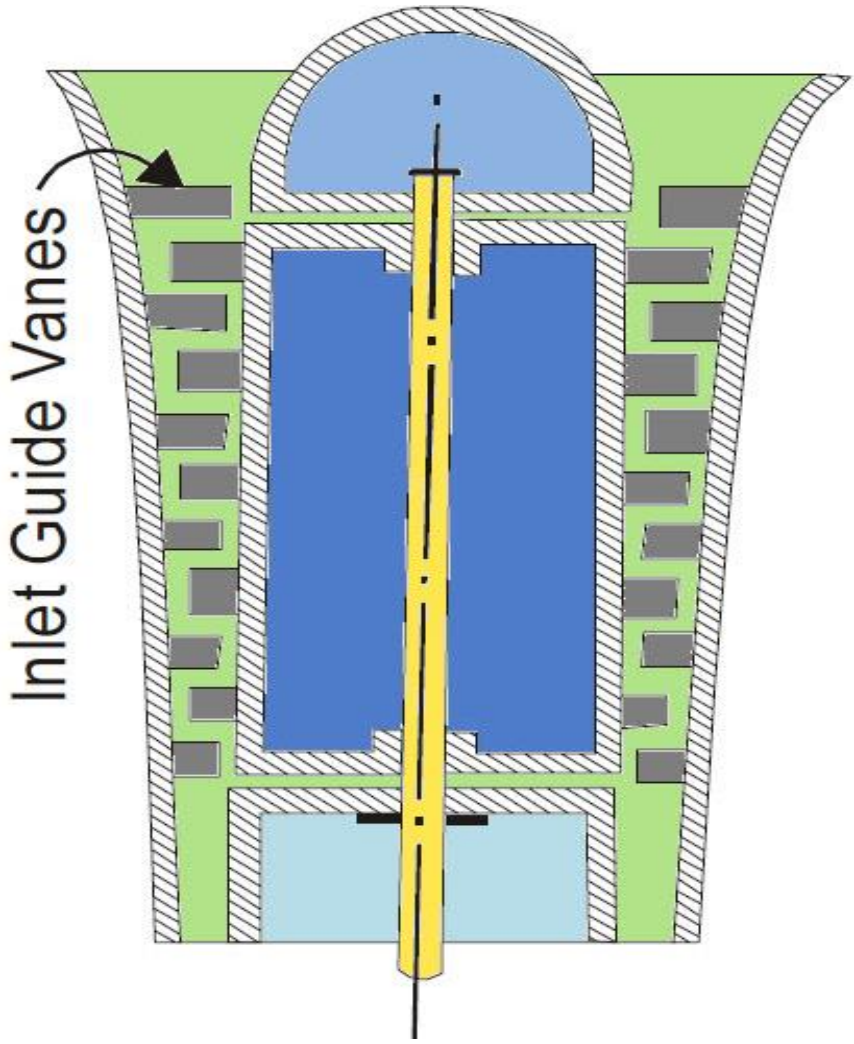

Figure3.6 Axial flow air compressor [5]

Axial flow compressors increase the pressure of the liquid by being accelerated in the rotating blades (blades), called (the rotor), and then distributed in the stationary blades (the stator).

The diffusion in the stator converts the speed gain gained in the rotor into a pressure rise. An additional series of fixed vanes (inlet guide vanes (IGV)) are normally installed at the inlet of the compressor to direct the air at the desired angle to the first stage of the rotary vanes. An additional diffuser is installed at the compressor outlet. It further diffuses the fluid before it enters the combustion chambers [10] and controls its velocity [32].

A satisfactory air filter is absolutely necessary to clean the air before entering the compressor, as the design of the wing profiles must be maintained. The deposition of dust particles on the blade surfaces reduces efficiency quickly [5]. The total pressure increase of a compressor of a modern gas turbine varies between 20: 1 and 40:1 [10].

The benefits of axial-stream compressor over diffusive compressor are high isentropic productivity (90-95%), high stream rate and little weight for a similar stream amount. The axial stream compressors are extremely delicate to the adjustments in air stream and speed, which result in fast drop in productivity [5].

3.3.1.2 Centrifugal Compressor

The centrifugal compressor comprises of an impeller (rotating part) and a diffuser (stationary segment) [5].

Air is taken in the center or "eye" of the rotor, as shown in figure (3.7). It is accelerated by the blades due to high rotational speeds of the rotor and is forced out radially from the rotor at high speeds. The air is then absorbed by the diffuser, which converts the high velocity into high pressure [10]. The impeller gives the air the high kinetic energy and the diffuser converts the kinetic energy into the printing energy [5].

The pressure increase per stage of a radial compressor varies between 1.5:1and 12: 1. Centrifugal compressors have a lower efficiency than axial compressors. Their main advantages are simplicity, strength and short length [10].

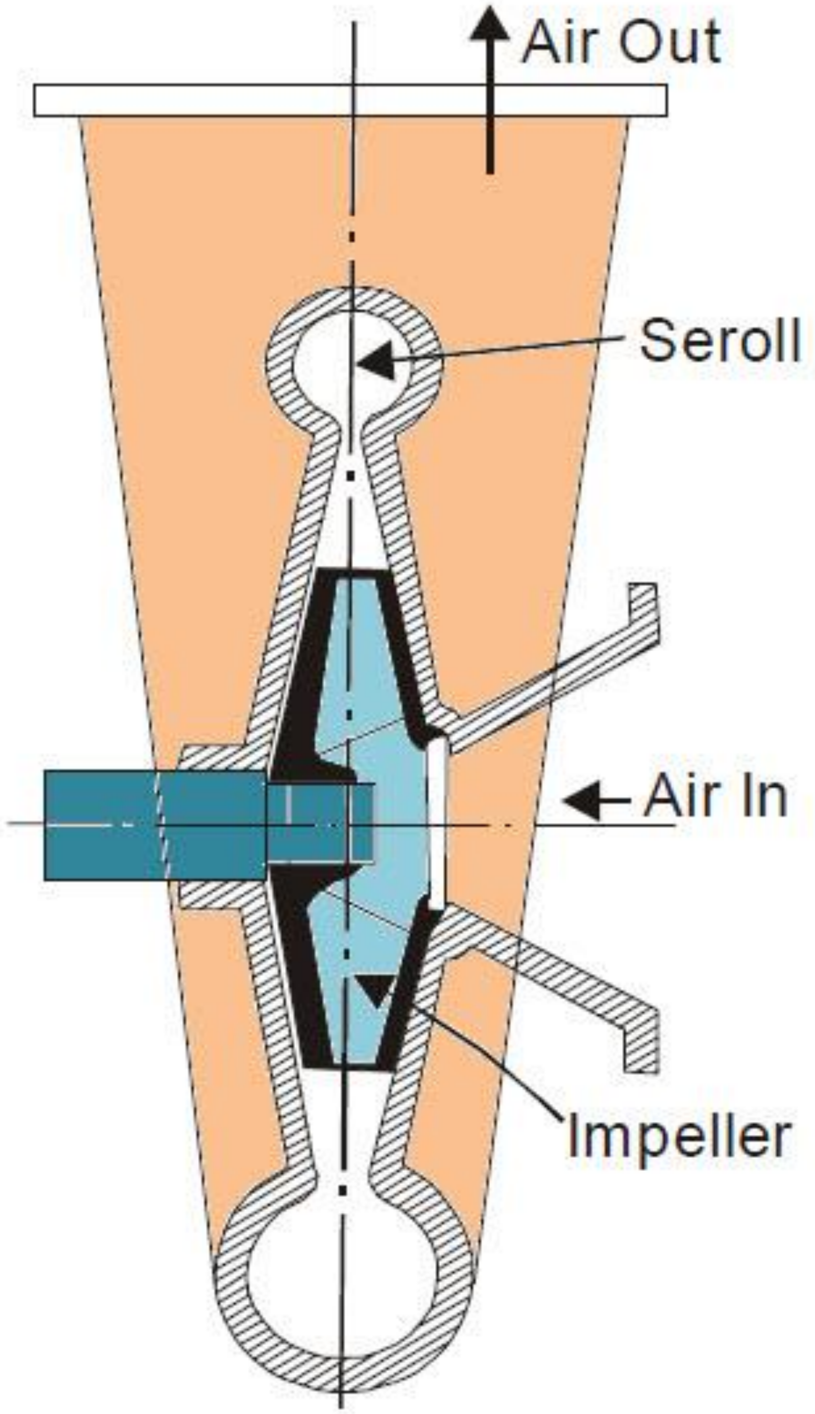

Figure3.7 Single stage single entry centrifugal compressor [5]

3.3.2. The Combustion Chamber

The combustor acknowledges air from the compressor and conveys it at a hoisted temperature to the turbine, along these lines the heat contribution to the gas turbine Brayton cycle is given by a combustor [32]. The stream rate of the burning gas is expected here to be the same as the air flow. The temperature at the inlet of the gas turbine is given as [19]:

$$T_f = T_d + \frac{W_f}{W} K_2 \qquad (3.4)$$

Where

W_f is rate the fuel flow, T_d is the air temperature deliver from combustor, T_f is the temperature at the inlet of the gas turbine

K_2 is the combustion chamber temperature rise coefficient.

In multiple type combustors, there is a fuel supply to each fire tube; however there are just a few igniters for every one of the tubes. At the point when ignition happens in the fire tubes having the igniters, the crossfire tube takes the hot gasses from the hot fire tube to ignite the remainder. This happens in a matter of one moment. Once the fire identifiers affirm stable start, the igniter will close down. The producers of gas turbines affirm that any fuel can be utilized if the vital changes are made to the fuel system [10].

Whole of gas turbine combustors gives a similar capacity; but, there are diverse strategies to manage combustors on the gas turbine. Generally the designs fall into three noteworthy classifications [32]:

1. Tubular (monocular can or side combustors)
2. Turbo-annular(can-annular)
3. Annular

3.3.2.1 Tubular (Side Combustors)

These combustors (shown in Figure 3. 8) are regularly installed on long European industrial turbines. Their attributes given as follows [10]:

1. Simple model
2. Ease maintenance
3. High life span

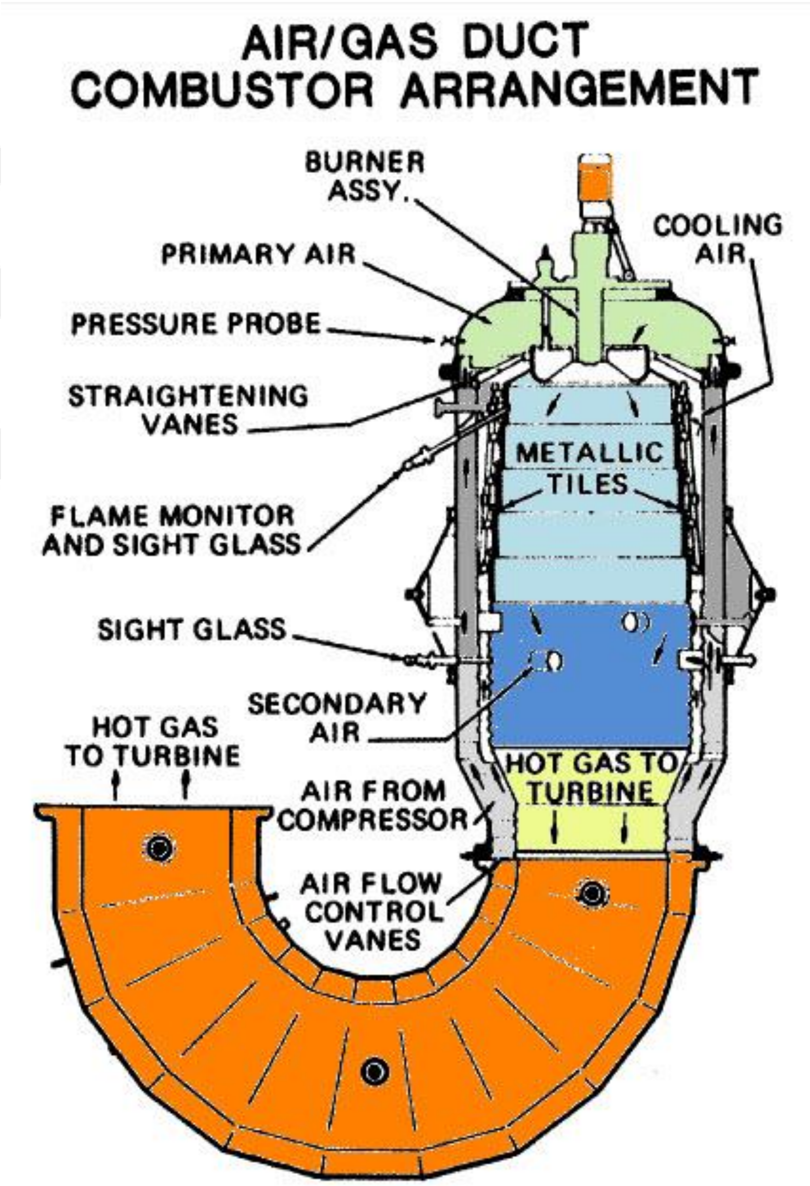

Figure3.8 Exemplary of single-can side combustor for a mechanical turbine [10]

3.3.2.2 Can-Annular

Most industrial heavy-duty gas turbines designed in the United States utilize can-annular combustors, as shown in Figure 3.9 [10]. The favorable position to these sorts of combustors is the simplicity of support. They likewise have a superior temperature appropriation than the side single-can combustor [32].

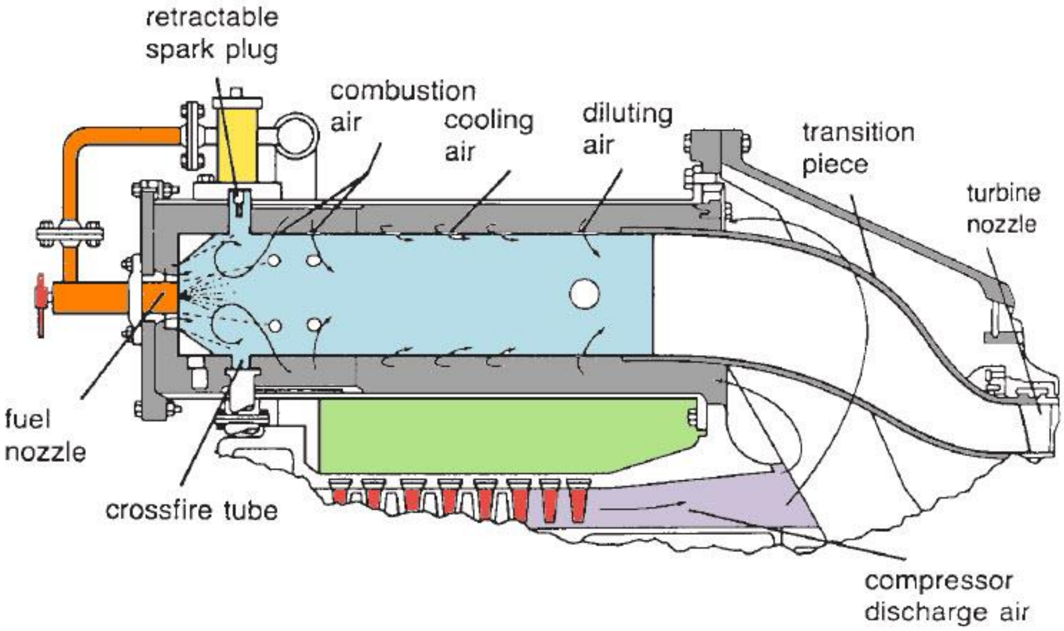

Figure3.9 A tubo-annular or can-annular combustor for a heavy-duty gas turbine (Courtesy of General Electric Company) [10]

3.3.2.3 Annular

Annular combustors are utilized for the most part in airplane sort gas turbine engines [10].

3.3.3 The Turbine

Operation can be extracted from a gas at a higher channel pressure to the lower back pressure by enabling it to move through a turbine [34]. In Figure 3.10, Brayton cycle is shown, the turbine efficiency can be expressed as (η_t) [33] :

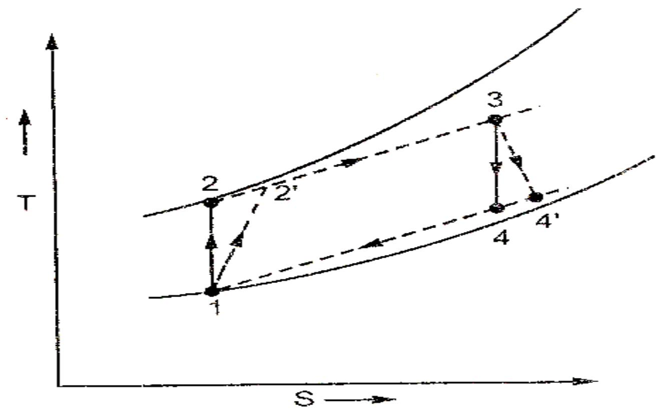

Figure3.10 Actual Brayton cycle [33]

$$\eta_t = \frac{T_3 - T'_4}{T_3 - T_4} \tag{3.5}$$

$$(T_3 - T_4)\,\eta_t = T_3 - T'_4$$

$$\left(1 - \frac{T_4}{T_3}\right)\eta_t = \left(1 - \frac{T'_4}{T_3}\right) \tag{3.6}$$

$$\frac{T'_4}{T_3} = \left[1 - \left(1 - \frac{1}{X}\right)\eta_t\right]$$

$$T'_4 = T_3\left[1 - \left(1 - \frac{1}{X}\right)\eta_t\right] \tag{3.7}$$

Where

$T'_4 = T_e$ = gas turbine exhaust temperature (°F)

$T_3 = T_f$ = gas turbine inlet temperature (°F)

$$T_e = T_f\left[1 - \left(1 - \frac{1}{X}\right)\eta_t\right] \tag{3.8}$$

$$P_{mg} = K_0\left(T_f - T_e\right)W \tag{3.9}$$

$$P_c = K_0(T_d - T_i)W \tag{3.10}$$

$$P_g = P_{mg} - P_c \tag{3.11}$$

Where K_0 is the output-factor of the gas turbine.

The work done by adiabatic development of burning gas in the turbine shows up as the turbine's mechanical output P_{mg}, it expressed in (3.9). Then again, the compressor devours power P_c to compressor air, it shown in (3.10). In this manner, the net yield of the gas turbine is its mechanical output P_{mg} less the compressor's power P_c, see (3.11) [19].

The two essential parts of the turbine are:

1. The stator nozzles,

2. The turbine rotor blades.

The stage comprises of a ring of settled spout cutting edges taken after by the rotor sharp edge ring [34].There are two sorts of turbines utilized as a part of gas turbine. These comprise of the hub stream and the outspread –inflow sort. The hub stream turbine is utilized as a part of over 95% of all applications [32].The basic sorts of turbines, which are being used, are hub stream sort. The essential prerequisites of the turbine are light in weighting, more proficiency; unwavering quality in working and lengthy working life [5].

Vast work yield can be acquired per arrange with big sharp edge speeds when the edges are intended to manage bigger burdens. More phases of the turbine are constantly favored in gas turbine control station since it diminishes the worries in the edges and builds the general existence of the turbine. More steps are additionally favored with rigid power stations since weight is not the actual thought in the outline which is basic in airplane turbine-plant [5].

The cooling of the gas turbine cutting blades is basic for long life as it is consistently undergo to big temperature gasses. There are distinctive strategies for cooling the edges. The regular technique utilized is the air-cooling. The air is gone during the openings given by the sharp blade [5].

3.3.3.1 Axial-Flow Turbines

Like its counterpart, the axial-flow turbine has a flow which enters and leaves in the axial direction [32]. Axial turbines are used in most compressible fluid applications. Then power of most gas turbines except the smaller ones.

Their efficiency is higher than for radial inflow turbines in most operating areas. Axial turbines are also used in steam turbine applications. However, there are significant differences between the design of axial turbines in gas turbines and those in steam turbine applications [10].

3.3.3.2 Radial-Inflow Turbine

The radial inflow turbine or inlet radial turbine has been in use for many years. In principle, a radial compressor with reverse flow and opposite rotation is about the smaller radial turbine than about the axial turbine. The figure (3.11) shows the component of a centrifugal turbine. Radial turbines do not start until now, because little has been known about them. Axial turbines are very popular due to their low frontal area and are therefore suitable for the aircraft industry. However, the axial machine is much longer than the radial machine, making it unsuitable for certain applications. Radial turbines are used in turbochargers and in some types of expanders. The radially inward turbine gasifies many components similar to a centrifugal compressor [32].

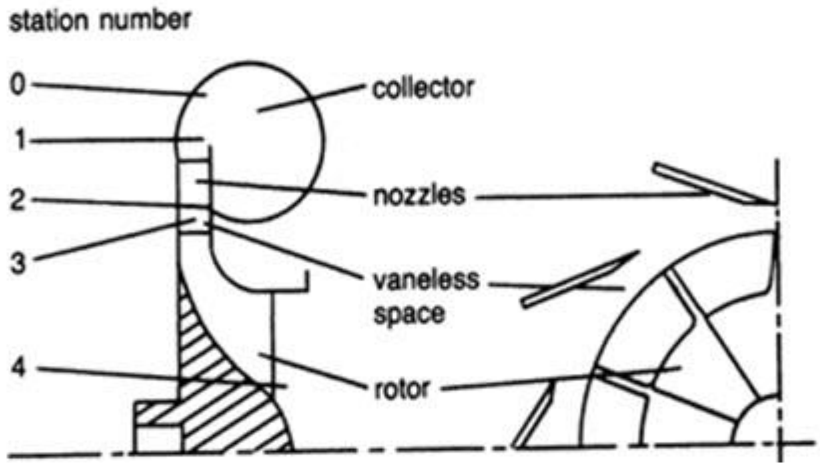

Figure3.11 Components of a radial inflow turbine

3.4 Control System Of The Gas Turbine

The control arrangement of the gas turbine has three sub control plans:

1. System of the speed control,
2. System of the Temperature control,
3. System of the Acceleration control.

The simplified version Rowen's model containing a solitary shaft gas turbine with control system is illustrated in Figure 3.12 [8].

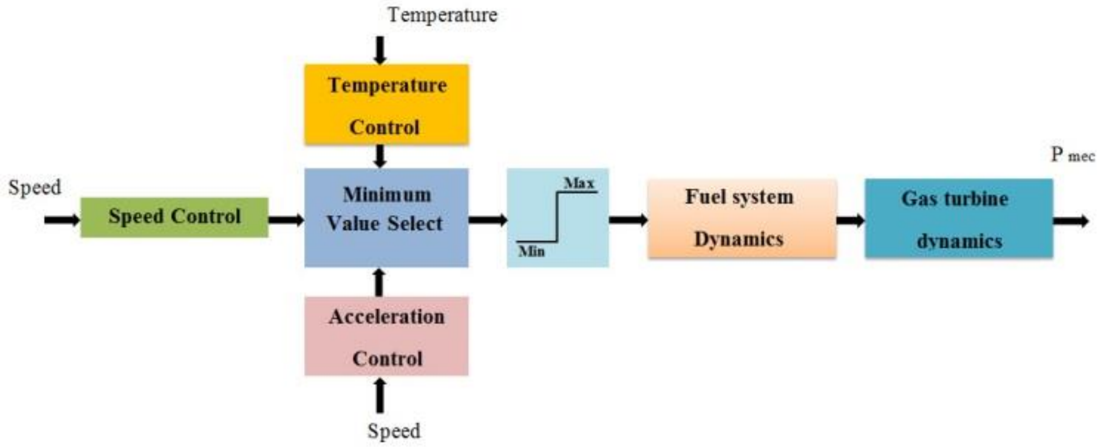

Figure3.12 Simplified Rowen's model for solitary shaft gas turbine with control system [8]

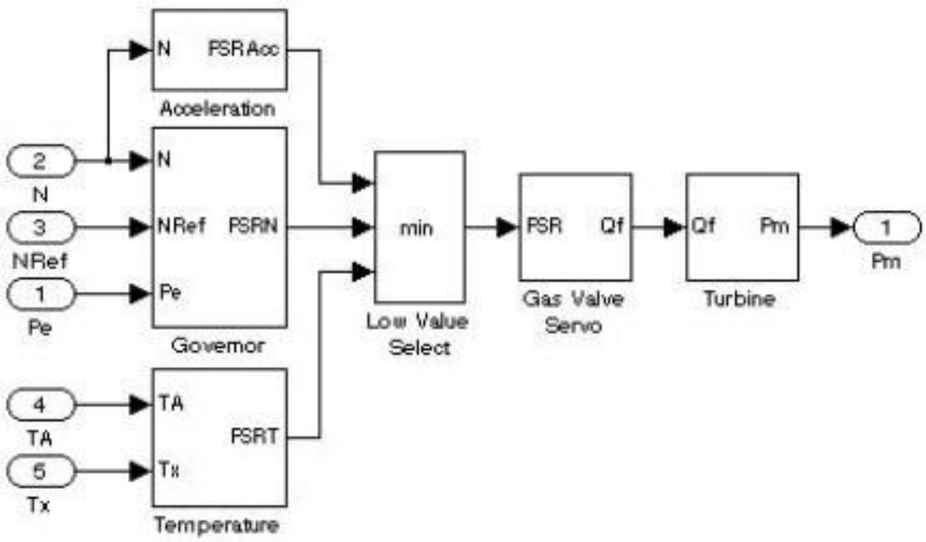

Figure3.13 Gas turbine Simplified block diagram [32]

Figure 3.13 shows a simplified block diagram of a Speedtronic control system with the following input / output signals: speed (N), speed reference (NRef), power (Pe), outside air temperature (TA) gas temperature (Tx) and mechanical power (Pm). Figure 3.13 shows only the main components: the turbine, the gas valve and its servo, a minimum value selector and three control blocks (acceleration, regulator and temperature). At the input of the minimum selector gate, several signals are competing for the gas valve control [32].

3.4.1 Speed Control

It is one of the important control schemes through ordinary operating conditions including its controlling changeable (the fuel demand) with a heat control system and an increasing speed control. All three unique controllers' outputs are contributions to a base entryway, which chooses the minimum amount of the fuel for three demands. The fuel demand is then sent to the gas turbine system [9]. The speed governor is the fundamental function to control the power generation by controlling the valve position of the fuel system [10].

The block diagram for speed governor of BGPP is shown in Figure 3.14. Were w is the gain (=1/droop (P.U. MW/ P.U. speed)), X and Y governor lead lag time consistent and Z is the governor mode (1=droop, 0=isochronous) [18].

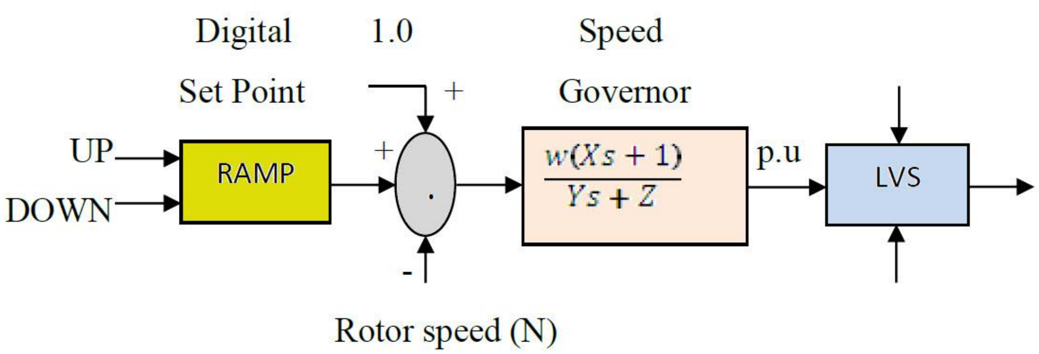

Figure3.14 Speed governor of HDGT

The droop controller (Z=1) is a proportional block, used to manage the turbine output power during operation. The droop controller responds to genuine velocity deviations from the reference velocity.

The appraised esteem 1.0 p.u. can then be recouped by appropriately modifying the power set-indicate agreeing the turbine capacity.

The error of the governing system is characterized as the distinction between the required (speed set point) and the deliberate speed (feedback). The pick-up of the representative is the adjustment in valve position (e.g., 10 percent) accomplished for 1 percent change in turbine speed blunder. The pick-up is kept up low to give a huge dependability edge to the administering system [10].

3.4.2 Temperature Control

The temperature control is active under abnormal operating conditions. The exhaust temperature is measured by a set of thermocouple merge radiation shields [23] located at the outlet of the turbine around the outer surface providing an input to the minimum gate. The control system then compares the turbine exhaust gas temperature value with the desired value of the set point. The change between these values is referred to as a temperature error. If the temperature error deviates from zero, the control system sends a signal to open the fuel valve to reduce this error [10].

The exhaust temperature control of BGPP is shown in Figure 3.15. The temperature (T_e) of the exhaust gas turbine expressed as [18]

$$T_e = F_1 = T_r - 700 * (1 - W_F) + 550 * (1 - N) \qquad (3.\ 12)$$

Here

T_e is the exhaust temperature, °F

T_R is the reference temperature, °F

N is the rotor speed [rpm]

W_F is the rate of fuel flow.

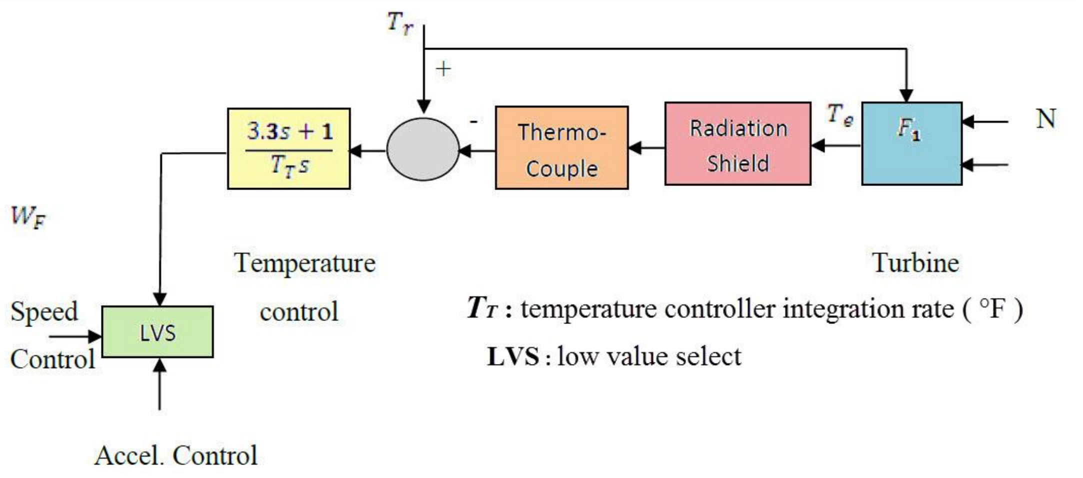

Figure3.15 Exhaust temperature control of HDGT

3.4.3 Acceleration Control

The acceleration control system is active in the situation of abnormal working conditions. The feedback in this control configuration is used for two purposes:

1. Enhancing the damping of the speed of control system by giving the secondary stabilizer term of that,

2. A load refusal is to be protected over speed upon [10].

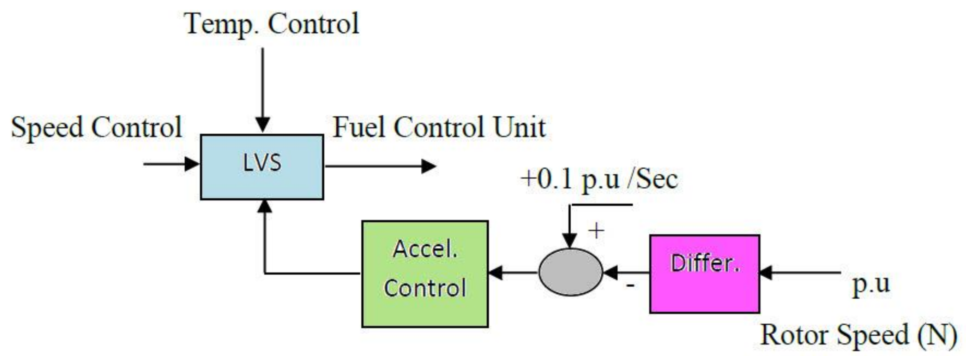

Figure3.16 Acceleration control of HDGT

3.4.4 Fuel Control System

Figure (3.17) shows the fuel control unit to HDGT, where W_{min} is minimum fuel flow (a, b and c) are valve positioner, T_F is the fuel control time consistent, E_{CR} is the ignition response time delay, E_{TD} is the turbine and exhaust delay and T_{CD} is the compressor release volume time steady [18].

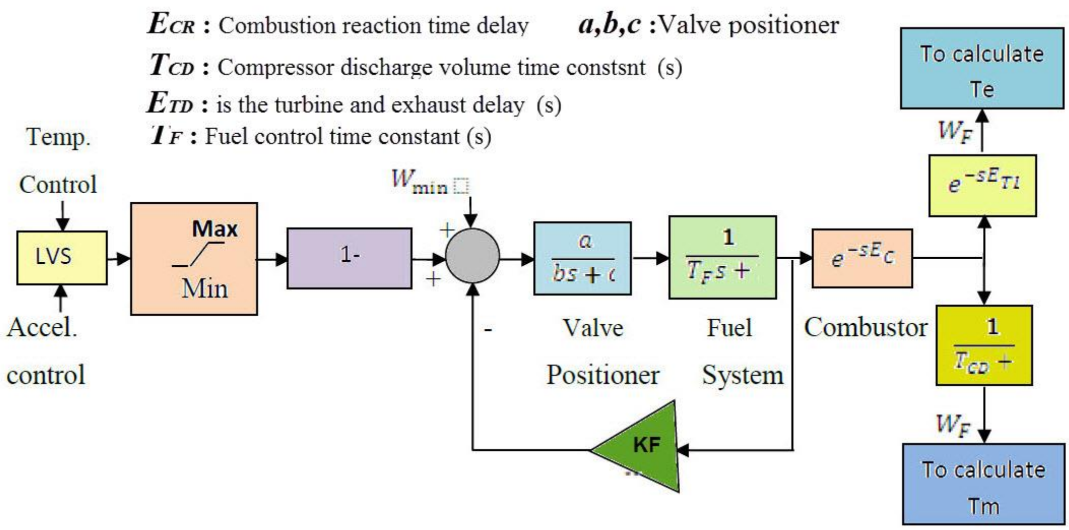

Figure3.17 Fuel control unit of HDGT

The fuel demand signal is generated from the LVS and then fed to the gas turbine model; by a block which sets the corresponding limits. The upper fuel limit limits fuel demand, which is physically unattainable. The lower fuel demand limit ensures that the fuel supplied to the burners is always enough to keep the flame alive under all operating conditions. The W_min offset takes into account the minimum fuel limit under unloaded, self-sustaining conditions required to service the compressor. Two time constants (b and T_F) model the valve positioner and the downstream pipeline or gas distribution system [9].

Because of the way that HDGTs can work with fluid and gasoline, the gasoline system designs are basically two unique systems with similar blocks. In bigger HDGTs both fuel systems are provided with internal circle criticism that detects the present situation of the valve and kills the mistake between set point and position signs. Hence, just a single time constant will show up which is in the valve positioner piece. Besides, in fluid fuel systems, there is a sidestep path from the fuel pump yield to the pump area. Sidestep way is introduced in Rowen's model by the feedback loop gain K_F [4]. The estimation of K_F is expressly computed to drive the general valve positioner-fuel system loop pick up to solidarity. Accordingly, the result of K_F and c

(Valve positioner piece) ought to end up noticeably zero, i.e., the K_F esteem is zero for our huge HDGTs if is definitely [4].

Actually there is a little time delay between the fuel infusion and warmth discharge in the combustor which is called ignition response delay. In present day systems it is the order of some mili seconds. This time postponement is actualized in Rowen's model as a period delay after the valve systems [4].

3.4.5 Gas Turbine Dynamic

The turbines behavior is reflected in two quantities. First the output torque and secondly the exhaust gas temperature [4].

The output of the fuel system block (i.e., the actual fuel flow) is both used in the calculation of exhaust temperature and fed to the next dynamic block representing the gas turbine and shown in Figure 3.18. Further, the mechanical turbine torque is calculated (F2) in the equation (3.13) [18] and multiplied by the rotor speed to obtain the actual mechanical machine power of the machine expressed in the equation (3.14) dynamically driving the generator.

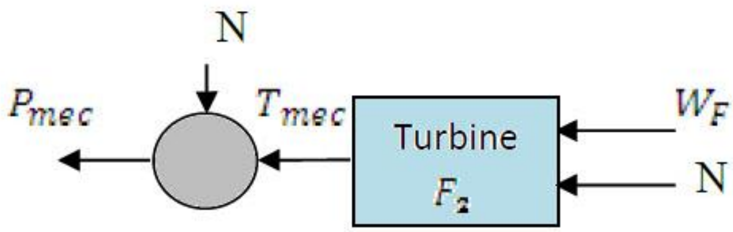

Figure3.18 Gas turbine dynamic of HDGT

$$T_{mec} = F_2 = 1.3 * (W_F - 0.23) + 0.5 * (1 - N) \quad (3.13)$$

$$P_{mec} = T_{mec} * N \quad (3.14)$$

Where

T_{mec} is the mechanical torque

P_{mec} is the mechanical power,

W_F is the fuel stream (flow)

N is the rotor speed.

For simple operation of the gas turbine without heat recovery, the IGVs would only be operational during start-up and shutdown of the gas turbine. However, the IGVs are also modulated in partial load operation if the gas turbine is used as part of a combined-cycle power plant. During normal operation of the gas turbine, the IGV would normally not be in operation, so it can be omitted [23].

In the simple circular gas turbine without IGV, it is essentially assumed that the air flow is fixed (with small variations) [22].

3.5 Fuel Type

Natural gas is the fuel of choice wherever it is accessible in light of its clean burning and its competitive cost [33]. Crude oil is being used as gas turbine fuel on the Middle East and other places where it is economically available [30].

Oil or gaseous petrol is the fuel of decision, gas turbines and joined cycle plants are the power station of decision as they change over the fuel into power productively and cost viably [33].

3.6 Auxiliary Systems

Auxiliary systems are the foundation of the gas turbine station. Without any assistant of system, the very presence of the gas turbine is impossible. It allows the auxiliary system of the gas turbine. The auxiliary system contains beginning, ignition, grease and fuel system and control [5].

3.6.1 Starting Systems

Two separate systems starting and ignition are required to guarantee a gas turbine motor will begin attractively. During engine start, the two systems must work concurrently.

The followings are the different types of gas turbine starter:

1. **Electrical:**

(*i*) AC what's more, (*ii*) DC

AC cranking motor are normally 3 phase induction types evaluated to work on the accessible voltage and recurrence. DC starter motor takes the source of electrical vitality from a bank of batteries of adequate ability to deal with the beginning load. Connecting with or separating clutch is utilized.

2. **Pneumatic or Air Starter:**

   Air starting is utilized generally since it is light, straightforward and conservative to work. As air starter engine has a turbine rotor that transmits control through a diminishment apparatus and grasp to the starter output shaft that is associated with the motor. The starter turbine is turned via pneumatic force taken from an outside ground supply, from an assistant power unit conveyed in the air ship or from a motor that is running. An electrical control unit controls the air supply to the starter by opening the weight diminishing valve. At the point when a motor starter is chosen and is naturally shut at a predetermined starter speed the grasp additionally consequently separates as the motor quickens. It is most appropriate for gaseous petrol pipeline gas turbine drive.

3. **Combustion Starter:**

   It is in every respect a small gas turbine.

4. **Hydraulic Starting Motor:**

   It comprises of a hydraulic driven starter motor for main engine, an aggregator, a hydraulic driven pump engine for assistant power unit. It is suitable for aircraft engine better [5].

3.6.2 Ignition Systems

The ignition system is used to trigger a spark during start-up. As soon as it is started, the combustion is continuous and the work of the ignition system is automatically switched off. The ignition system types [5] are listed below:

1. Capacitor release (discharge) system.

(a) High pressure (tension) system and (b) Low strain system.

2. Induction system.

3. A C power circuits

3.6.3 Lubrication Systems

A solitary greasing up system is generally utilized for overwhelming casing gas turbines and driven hardware utilizing mineral oil. A few applications utilize manufactured greasing up oil because of its heat proof property. However, higher-consistency oils can be utilized as a part of high-encompassing temperature regions. Substantial edge and power turbines utilize oil-film bearings [10].

3.6.4 Fuel System

Fuel system in gas turbine essentially has two sub-system low weight and high weight. The low-weight system comprises of a fuel tank, support pump, strainer, double fine oil channels, and common valves. The high-weight system comprises of primary fuel pump, help valve, strainer, fuel control, closed off valve, stream distributor and nozzles [5].

3.7 Operation of Gas Turbine

3.7.1 Starting

Starting sequence of any gas turbine from rest to its rated speed requires a specific request of occasions to be refined either physically or automatically. The actual steps in arrangement are turning, start, quickening, and administering.

Status sequence of gas turbine is as follows:

1. Application of control power enlightens every one of the glitches lights.

2. Work 'Reset change' to reset breakdowns circuits: By doing as such, glitch lights go off and all control gadgets accept the condition for beginning.

3. Work "Begin" change to start beginning arrangement. By doing this, lube oil pump and cooling fan begin. In the event that there are separate switch for these, work these.

4. At the point when lube oil achieves a preset pressure, the starter is empowered and turning of the motor starts.

5. With the cranking of beginning of starter, the motor and debilitates pipes are cleansed of any flammable gasses that may be available.

6. During the cranking cycle, the fuel support pump is utilized and worked to build fuel pressure.

7. When the fuel pressure the wrenching cycle, the fuel support pump is utilized and worked to build fuel pressure has achieved an endorsed least esteem, fuel and start switches are turned on given a preset turbine speed has been come to.

8. The turbine quickens because of burning of fuel and help of turning engine. At a preset esteem, say in the request of 70% of evaluated speed, the starter and start are cut-off automatically.

9. The turbine winds up plainly self-supporting and quickens all alone to its represented speed till the administering system assumes control over the control [5].

3.7.2 Shut Down Procedure

To stop the gas turbine, the fuel supply should be closed. This is refined by shutting the fuel valve either physically or by de-enabling an electrically worked valve. In circumstances where sleeve directions are used, stream of lube oil to course after shutdown is fundamental for cooling [5].

The economic parts of power generation by gas turbines is ended up being all the more engaging, on account of low capital cost, and high enduring quality and flexibility in operation. Quick start and capacity of using wide arrangement of stimulates from combustible gas to remaining oil or powdered coal are other extraordinary components of gas turbine control plants. Genuine progress has been made in three orientations specifically augment in unit cutoff points of gas turbine unit, increase in their capability and drop in capital cost. Basic utilization of gas turbine plant is to supply crest stack [34].

3.8 Applications of Gas Turbine

The utilizations of gas turbines are:

1. Gas turbine plants are utilized as standby plants for the hydro-electric power stations.

2. Gas turbine control plants may be used as pinnacle burdens plant and standby plants for tinier power units.

3. Gas turbines are utilized as a part of fly airplanes and boats. Pummeled fuel let go plants are utilized as a part of train [5].

3.9 Advantages of Gas Turbine Power Plant

The financial aspects of energy era by gas turbines is turned out to be more appealing, because of low capital cost, and high unwavering quality and adaptability in operation. Fast beginning and ability of utilizing wide assortment of fills from petroleum gas to leftover oil or powdered coal are other extraordinary elements of gas turbine control plants. Significant advance has been made in three headings to be specific increment in unit limits of gas turbine unit, increment in their proficiency and drop in capital cost. Essential utilization of gas turbine plant is to supply peak load.

Be that as it may, the upsides of gas turbine are:

1. It is littler in size and weight when contrasted with a comparable steam control plant.

2. Because the underlying expense and working expense of the plant is lower, gas turbines are every now and again utilized for crisis administration and taking care of day by day top loads on a system [30].

3. The station wants less water when contrasted with a gathering steam control plant.

4. The plant can be started quickly, and can be put on load in a brief span.

5. There are no standby misfortunes in the gas turbine influence plant though in steam influence plant these misfortunes happen on the grounds that kettle is kept in operation notwithstanding when the turbine is not providing any load.

6. The repair of the plant is less demanding and upkeep cost is low.

7. The oil of the plant is simple. In this plant grease is required for the most part in compressor, turbine principle bearing and orientation of auxiliary equipment.

8. The plant does not require substantial establishments and building.

9. There is incredible improvement of the plant over a steam plant because of the nonattendance of boilers with their encourage water evaporator and consolidating system [5].

10. Power to weight proportion is superior to steam turbine.

11. Overall effectiveness of gas turbine plant is superior to anything that of steam turbine plant [34].

3.10 Exciter System

The main function of an excitation system is to generate direct current (DC) on the field windings of the synchronous generator. In addition, the excitation system performs control and protection functions to achieve optimum system performance by controlling the field voltage and the field current. The excitation system must be able to respond to a transient dynamics with field constraints with generator instantaneous and short-term capability. From a power grid perspective, the excitation system should be available in voltage control and amplification of system stability. In addition, it should be able to react quickly to a disturbance to improve transient stability. In addition, it should be able to modify the generator field to improve the stability of the small signal [11].

From the viewpoint of the energy system, the excitation system should contribute to the effective control of the voltage and to improve system stability. It should be able to respond quickly to a disturbance to improve the transient stability and modulate the generator field to improve the stability of the small signal [11].

Three unique sorts of excitation systems are determined on the premise of excitation power source, as takes after:

1 Type DC excitation systems, which utilize an immediate current generator with a commutator as the source of excitation system control (old type).

2 Type AC excitation systems, which utilize a generator and either stationary or rotating rectifiers to deliver the immediate current required for the synchronous machine field.

3 Type ST, in which excitation power is provided through transformers or assistant generator windings and rectifiers [12].

Figure 3.19 demonstrates the useful graph for an extensive synchronous generator with its excitation system [11].

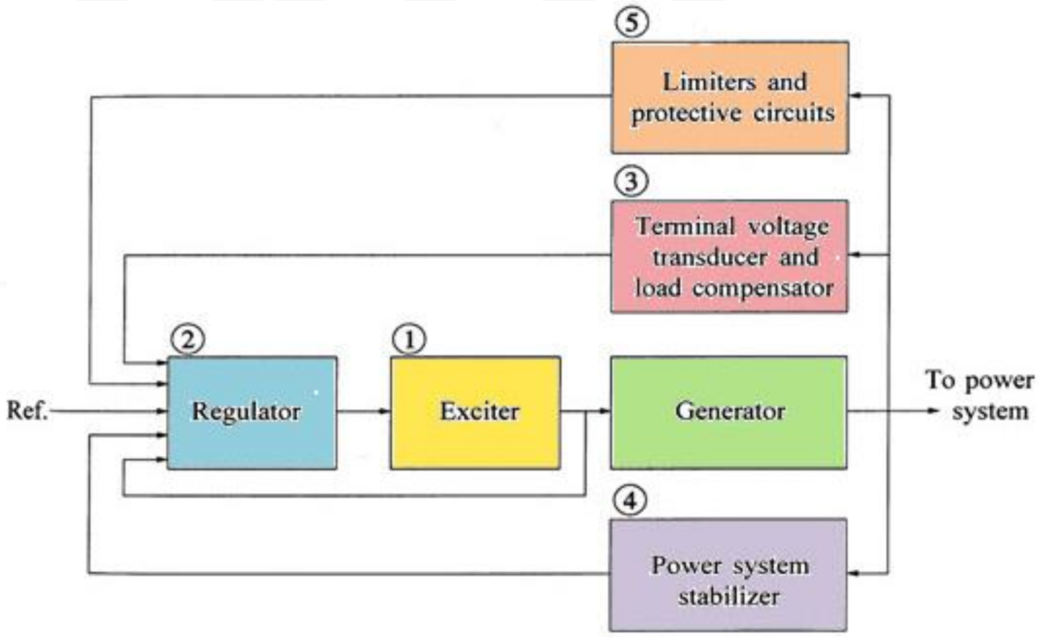

Figure3.19 Function block diagram of an excitation system with power system stabilizer

The A.C. terminal voltage of the synchronous generator is detected by a potential transformer, rectified and filtered, and then compared with a voltage reference to V_REF to obtain voltage deviation ΔVt. After being amplifier, the signal used to control the exciter field and the exciter output to turn to control the generator field excitation. The negative feedback works in such a way that the excitation will be increased whenever the terminal voltage drops below the voltage reference level and decreased whenever the terminal voltage rises above the voltage reference level [36].

3.10.1 Terminal Voltage Transducer and Load Compensator

A schematic diagram of the terminal voltage converter and the load compensator is shown in the figure 3.20 [12].

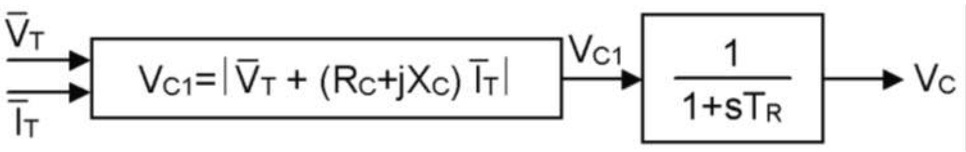

Figure3.20 Terminal voltage transducer and elective load compensation components

If no load compensation is used (R_c = X_C = 0), the block diagram is reduced to a simple measuring circuit. The terminal voltage of the synchronous generator is detected and normally reduced to a DC quantity. While the filtering associated with the voltage converter can be complex, it can normally be reduced to the shown time constant T_R for modeling purposes. This time constant is very small for many systems and care should be taken to set it to zero [12].

3.10.2 Exciter AC7B

The excitation system of BGPP is of AC7B type and shown in Figure 3.21 AC7B type excitation system is proposed by IEEE Task force. The actual data of the excitation system are taken from manufacture’s data sheets. BGPP excitation system includes a inner feedback which regulates generator field voltage or exciter current, an exciter current limiter, VFEMAX, to ensure the field of the generator, and the proportional integral derivative (PID) based alternator voltage controller (AVR) [12].

3.10.3 Power System Stabilizer (PSS2B)

PSSs are used to enhance damping of power system oscillations through excitation control. Commonly used inputs are shaft speed, terminal frequency, and power.

Control system stabilizer (PSS) gives a further info signal to the exciter system to upgrade damping of the power system through exciter control. Generally the info signs can be rotor speed deviation, accelerating force, or frequency deviation. The power system stabilizing signals control the exciter system and then enhancement of power system dynamics can be reached [11].

The PSS used in BGPP is of PSS2B type which is shown in Figure 3.22. The actual data of the PSS2B are taken from the manufacture’s data sheets. The PSS2B type PSS is a dual-input stabilizer which is the combination of power/speed or frequency to generate the stabilizing signal [12].

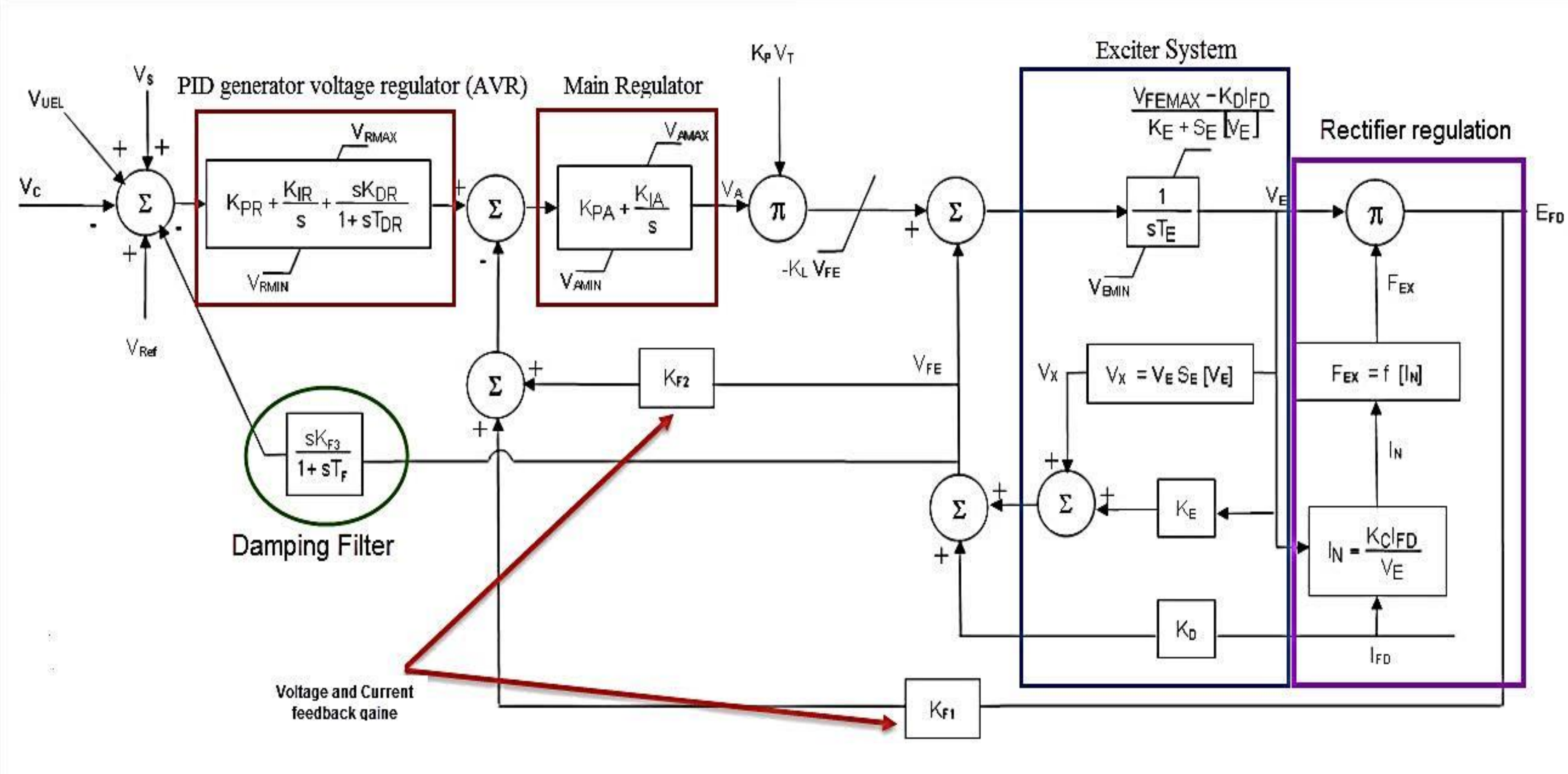

Figure3.21 Type AC7B—exciter system [12]

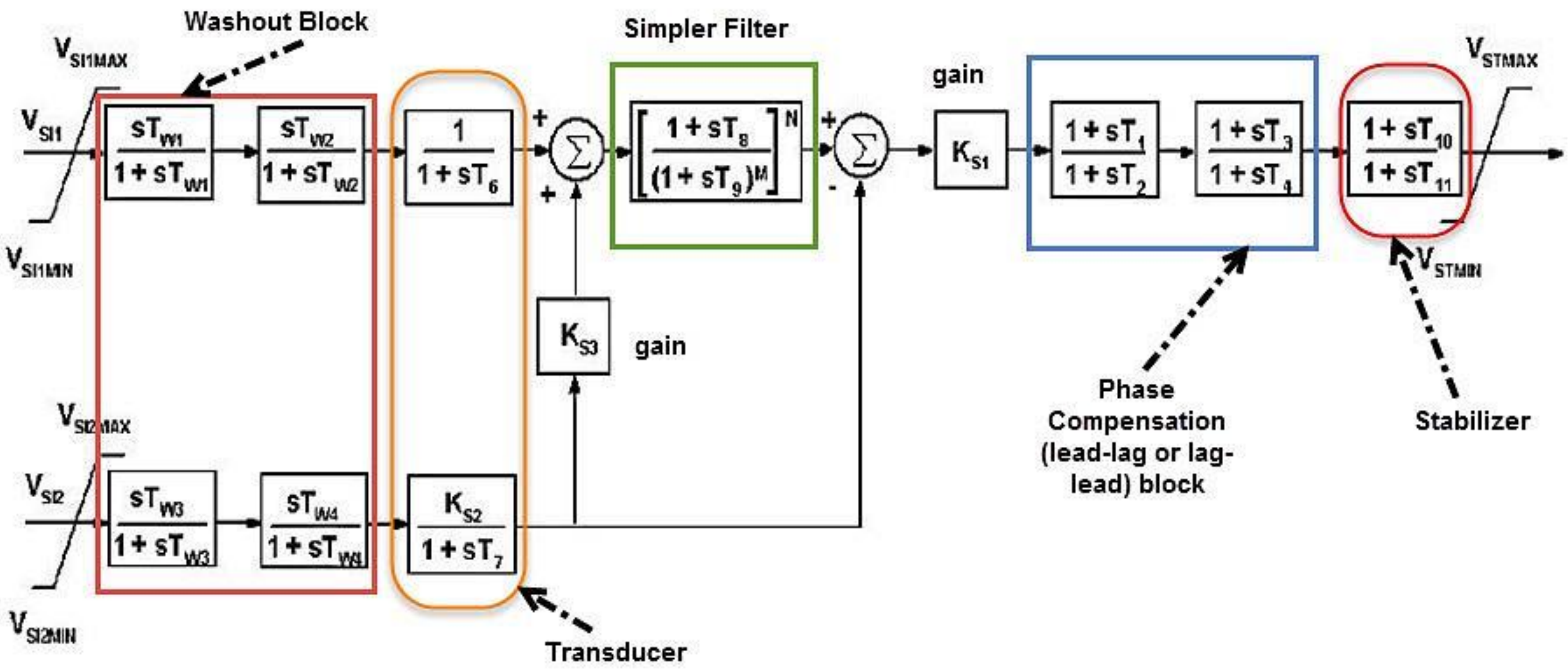

Figure3.22 Type PSS2B [12]

CHAPTER 4

SIMULATION OF BAZYAN GAS POWER PLANT

4.1 Introduction

The need for modeling and simulation of gas power plants with system controllers is decisive for the comprehension of their dynamic features. The overall plant is generally described by algebraic and differential equations which can be modeled using several blocks in simulation platform to describe linear or nonlinear behavior of the system [15].

Bazyan Gas Power Plant (BGPP) is a one-shaft, heavy-duty industrial gas turbine. The station includes four gas turbines which has a total installed capacity of rated 500 MW, with an actual capacity of 460 MW.

4.2 Synchronous Generator

The synchronous generator converts mechanical power into electrical power at rated voltage and frequency [36]. It is shape the main source of electric vitality in power system [11].

The source of the mechanical power, the prime mover, might be a diesel motor, a steam turbine, a gas or a water turbine. Whatever the source, it must have the essential property that its speed is practically steady paying little mind to the power request. The investigation of any power system to decide its strength includes the mechanical properties of the machines in light of the fact that, after any unsettling influence, they should modify the angle of their rotors to meet the conditions of power transfer forced [37].

The electrical data of the synchronous machine are given in Table 4.1.

Table 4.1 Synchronous machine data for (BGPP)

Parameter Description	Value	Unit
Type	GE 9A5	--
Rated-apparent power (SNgen)	142	MVA
Rated stator voltage (Un)	15	KV
Rated frequency (fn)	50	Hz
Rated speed (Wm)	3000	rpm

4.3 Step-up Transformers

The electrical model of BGPP contains step-up transformers to convert voltages from low to high values and then distribute the power through transmission lines. The technical data of the transformer are given in Table 4. 2.

Table 4.2 Step-up transformer data for (BGPP)

Parameter Description	Value	Unit
Type YNd11	--	-
Rated- apparent power (Snt)	150	MVA
Rated- primary voltage	15	kV
Rated- secondary voltage	132	kV
Rated (short-circuit) impedance at central tap (step up transformer rated apparent power) Zsc	0.125	p.u.
Xsc/Rc Ratio	50	(default value)

4.4 Gas Turbine System

In this study, the dynamic model of a simple gas turbine is developed using transfer function blocks. Gas turbine system incorporates an arrangement of mathematical conditions clarifying the steady-state elements of the gas turbine thermodynamics, time delays, and a couple of important controls that is said out of sight of the gas turbine.

In a gas turbine, the primary control circle changes the fuel stream to guarantee the right output power and recurrence and furthermore alters the air flow that control the exhaust gas temperature [38].

The typical parameters for gas turbine system are selected from Appendix A [5].

Figure 4.1 shows the model of the exhaust temperature control.

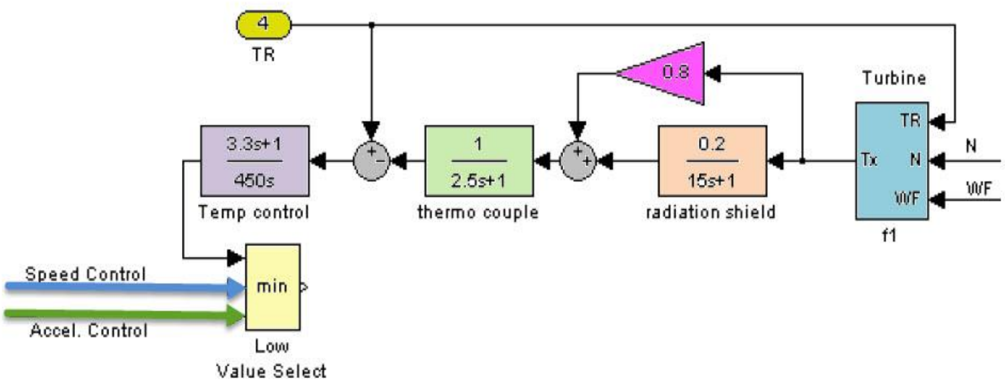

Figure 4.1 Model of the exhaust temperature-control.

The model of the acceleration control is illustrated in Figure 4.2.

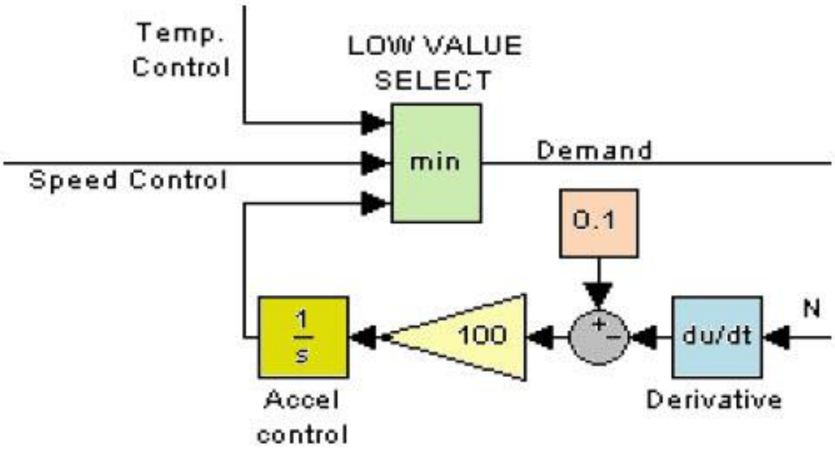

Figure 4.2 Model of acceleration control

The model of the fuel control system is shows in Figure 4.3.

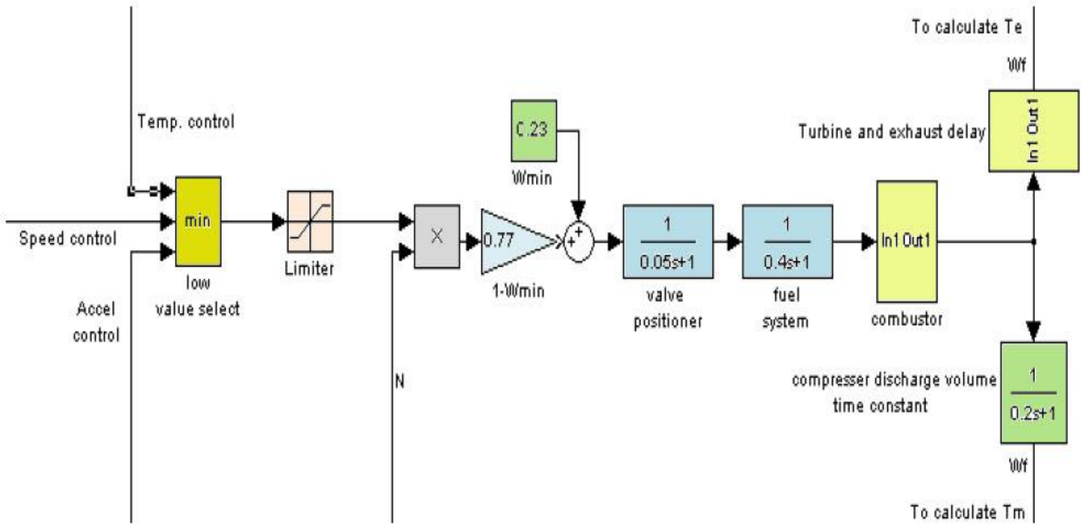

Figure 4.3 Model of fuel control unit

The model of the gas turbine dynamic is represented in the Figure 4.4.

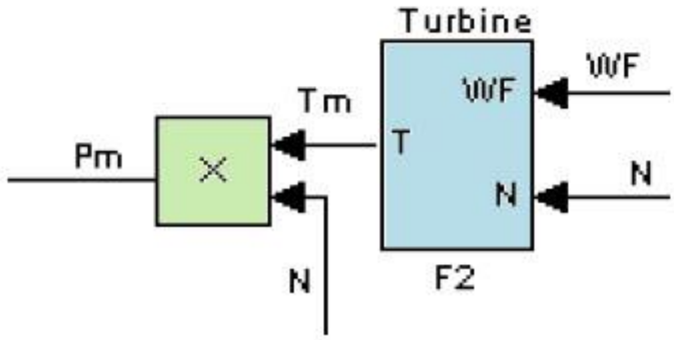

Figure 4.4 Model of gas turbine dynamic

Figures 4.1, 4.2, 4.3 and 4.4 are assembled together to build a complete model for the gas turbine system. The overall system model is shown in Figure 4.5.

Figure 4.6 shows the comparison of the exhaust air temperature in the actual data [5] to the result obtained from the simulation of the gas turbine in BGPP.

It can be commented that the two figures are close to each other. This situation explains that the gas turbine system model is practically verified.

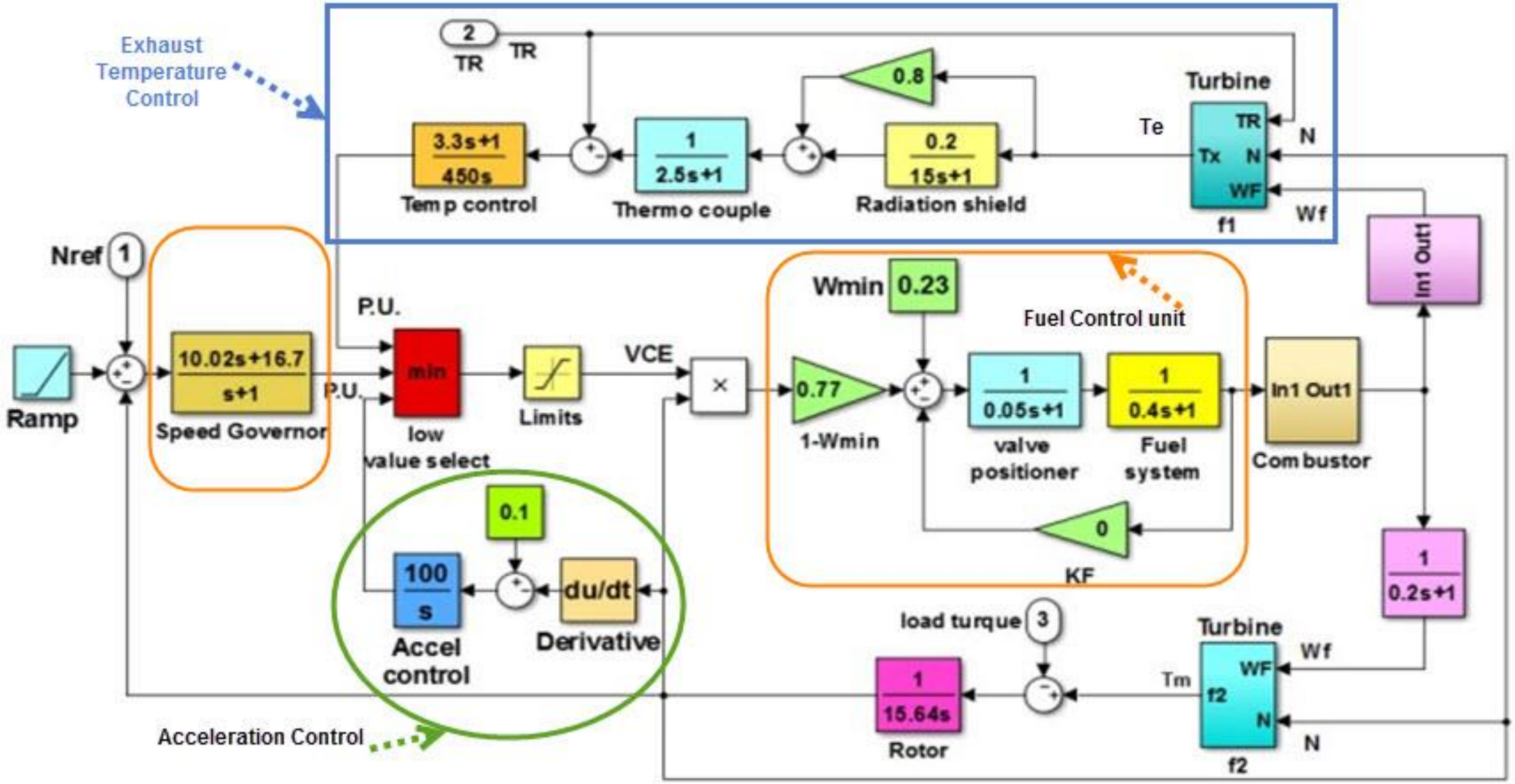

Figure 4.5 Overall gas turbine model with its controller [22]

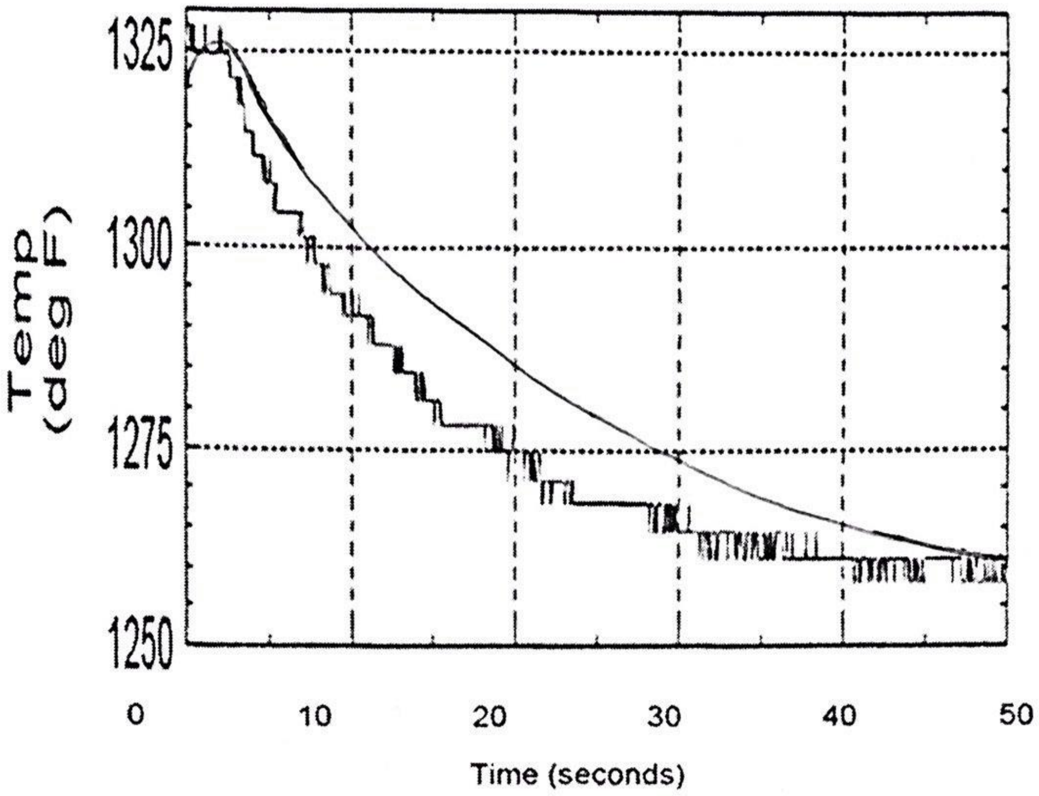

Figure 4.5 Comparison of the exhaust air temperature in the actual data [5] to the result obtained from the simulation of the gas turbine in BGPP.

4.5 Exciter System Model (AC7B)

The emulation model of the AC7B type exciter in BGPP is represented in Figure 4. 8. The typical parameters of the exciter system are selected from the manufacture's data sheets.

The specimen information for a Type AC7B exciter system with terminal voltage transducer is characterized in Appendix B [12].

4.6 Power System Stabilizer Model (PSS2B)

The simulation model of the PSS2B type PSS in BGPP is appeared in Figure 4. 9. The typical data of the PSS design are selected from the manufacture's information sheets.

The sample data for a Type PSS2B for Bazyan Gas Power Plant are defined in - Appendix C [12].

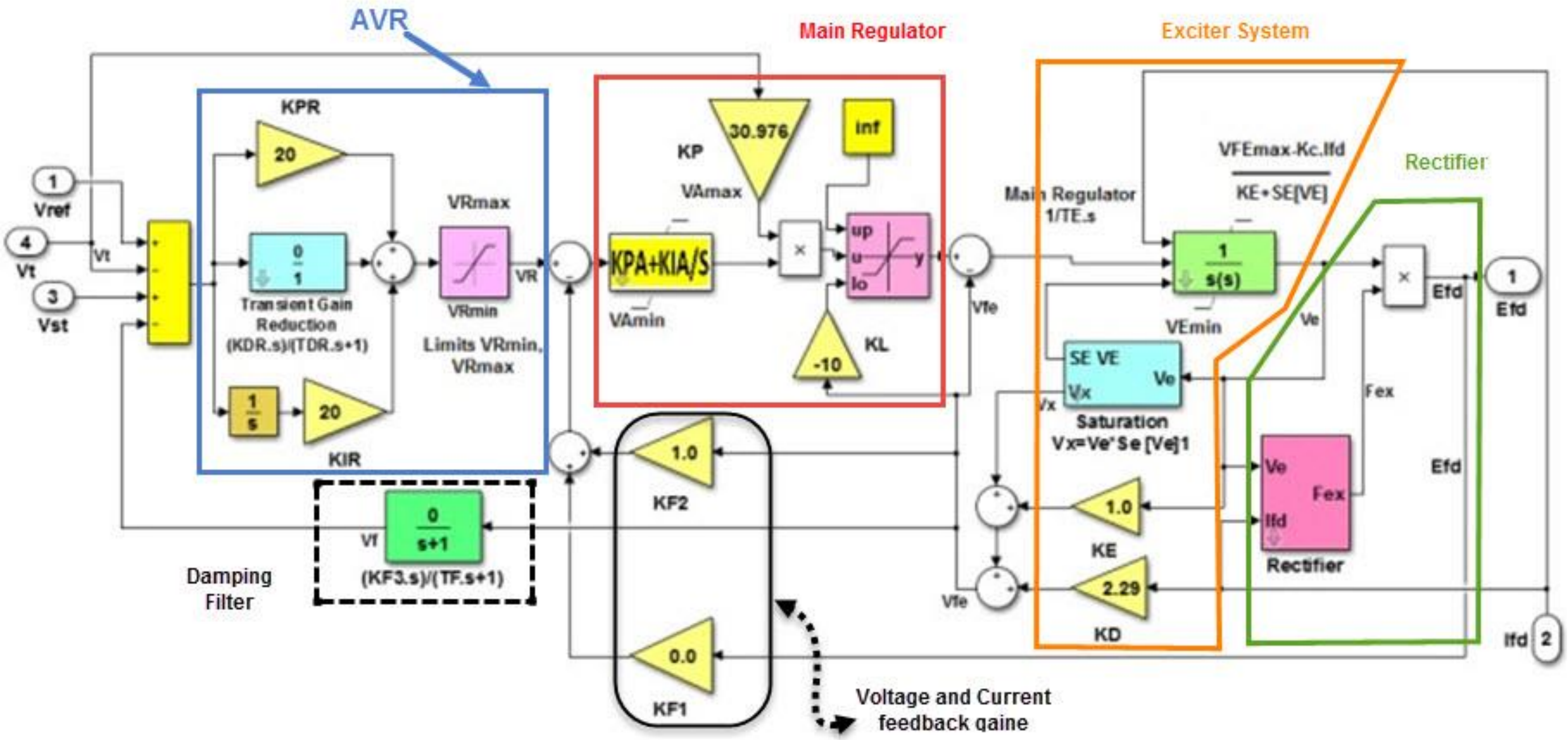

Figure 4.7 Exciter AC7B Models [12]

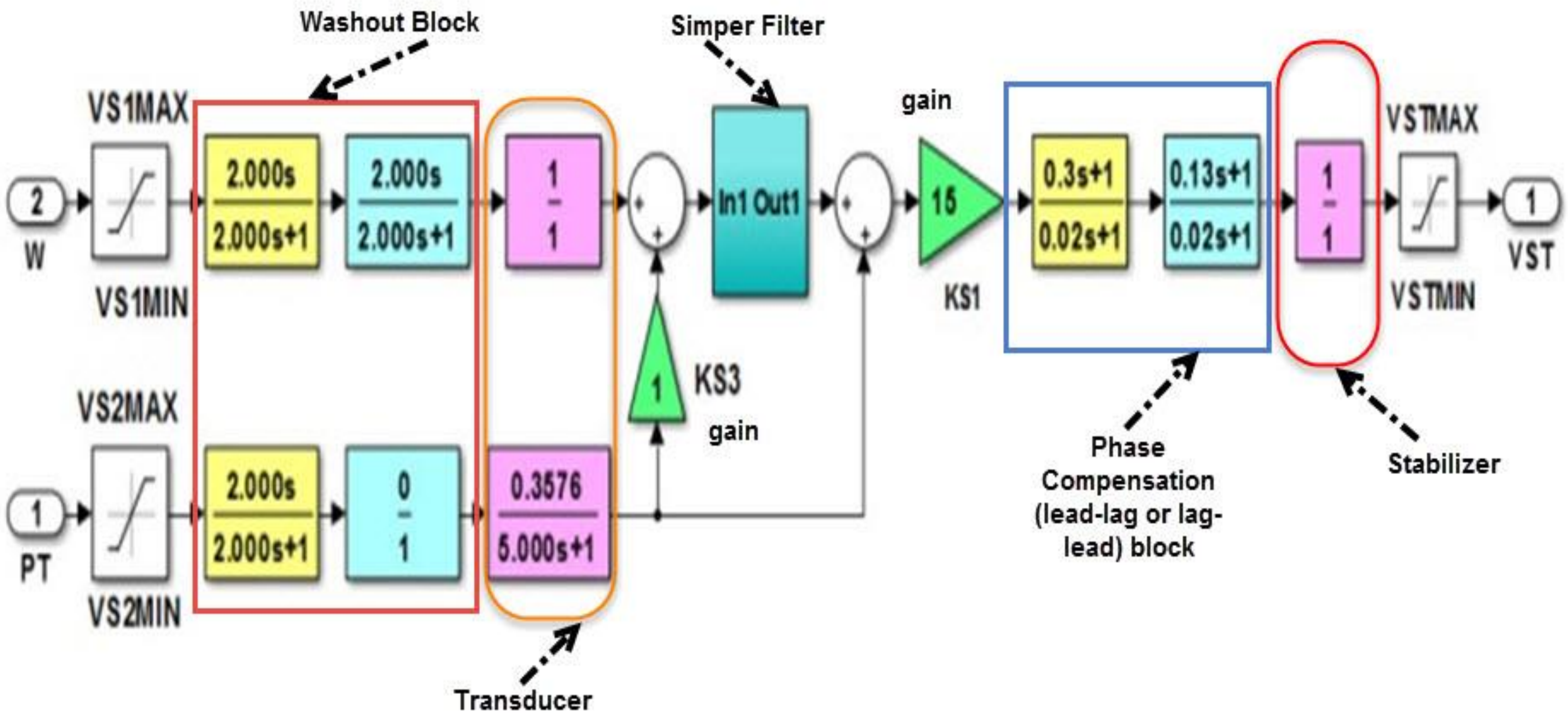

Figure 4.8 PSS2B Model [12]

4.7 Description of BGPP

The BGPP is a solitary axis, straightforward -cycle, heavy-duty gas turbine. This turbine can utilize either gas or fluid fuel. The Bazyan gas turbine cycle is a steady stream cycle with a consistent expansion of warmth vitality. It is alluded to as the Brayton Cycle [31].

The component of Bazyan gas- turbine consists of:

1. **The compressor :** The axial-stream compressor division comprises of the compressor rotor and the inclosing packaging. Included inside the compressor wrapper are the bay pioneer vanes, the 17 phases of rotor and stator edges, and the leave direct vanes [38].
2. **The combustion system:** The ignition system is a can-annular sort with 14 burning loads masterminded around the outskirts of the compressor release packaging.

This system additionally contains fuel spouts, spark plug start system, fire finders, and crossfire tubes. Hot gasses, delivered from consuming fuel in the ignition chambers, are utilized to drive the turbine.

Every one of the fourteen ignition corridor are interrelated by methods for crossfire tubes. These tubes qualify fire from the let go chambers to proliferate to the unfired chambers.

Ignition is beginning by methods for the exhausting from two high-voltages; retractable-cathode spark connects introduced to neighboring burning chambers (13 and 14).

Through beginning operation, it is essential that a sign of the nearness or nonappearance of fire be transmitted to the control system. Hence, a fire perception system is utilized comprising of four sensors which are introduced on four ignition chambers (4, 5, 10 and 11) and an electronic intensifier which is mounted in the turbine control board.

The double capacities fuel spouts are utilized as a part of gas turbines consuming either gas or oil energizes, with plausibility of exchange from one of the fuel to the next (double fuel unit) [37].

1. **The turbine:**The turbine part is an axial- stream sort and comprises of three stages. It change over the energy as high energy pressured gas, created by the compressor and ignition areas, in to mechanical energy [38].

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

Dynamic system models of power system components are utilized to simulate the electro-mechanical behavior when unsettling influences are applied. For system planning, this type of simulations is needed in order to design required operating conditions as well as to construct secure operating limits [39].

5.2 Simulation Studies

During system operation, the mechanical kinetic energy is varied between the electrical current flow through the system and the mechanical power at the rotating generator. After disturbances, the vibrations can become clear in numerous variables, whereby the accelerating flow of force is the most important. It shows the equilibrium point between the mechanical inputs and the electrical power.

Recently, high efficiency gas turbines having high efficiency have been developed, and gas turbine generators have been used in many energy systems. Modern gas turbine systems, however, are sensitive to frequency changes and could be subjected to cascade triggering during a large frequency dropout. The dynamic behavior of the gas turbine must then be analyzed for small and large frequency disturbances [17].

The synchronous generator in BGPP is a cylindrical rotor type with GE Frame 9E gas turbine along with their exciters (type AC7B- model-IEEE), PSS (PSS2B) and (AVRs).

The model of the electrical system in BGPP incorporates the progression -up unit transformers, to transformation the voltage from low volt to high voltage and then distributed it through the transmission line. The transformer technical datasheet is description in the Table (4. 2) [39].

The developed model is simulated for many disturbances. Such as a step change in governing input, one line-ground fault and three-phase fault at BGPP are selected for the simulation process. At each step, the variables rotor angle (δ), terminal voltage (V_T), acceleration power (P_{acc}) and rotor speed (W_m) are recorded and plotted.

The overall model of BGPP consisting of four units is shown in Figure 5.1, while the modeling details of one unit is represented in Figur.5.2.

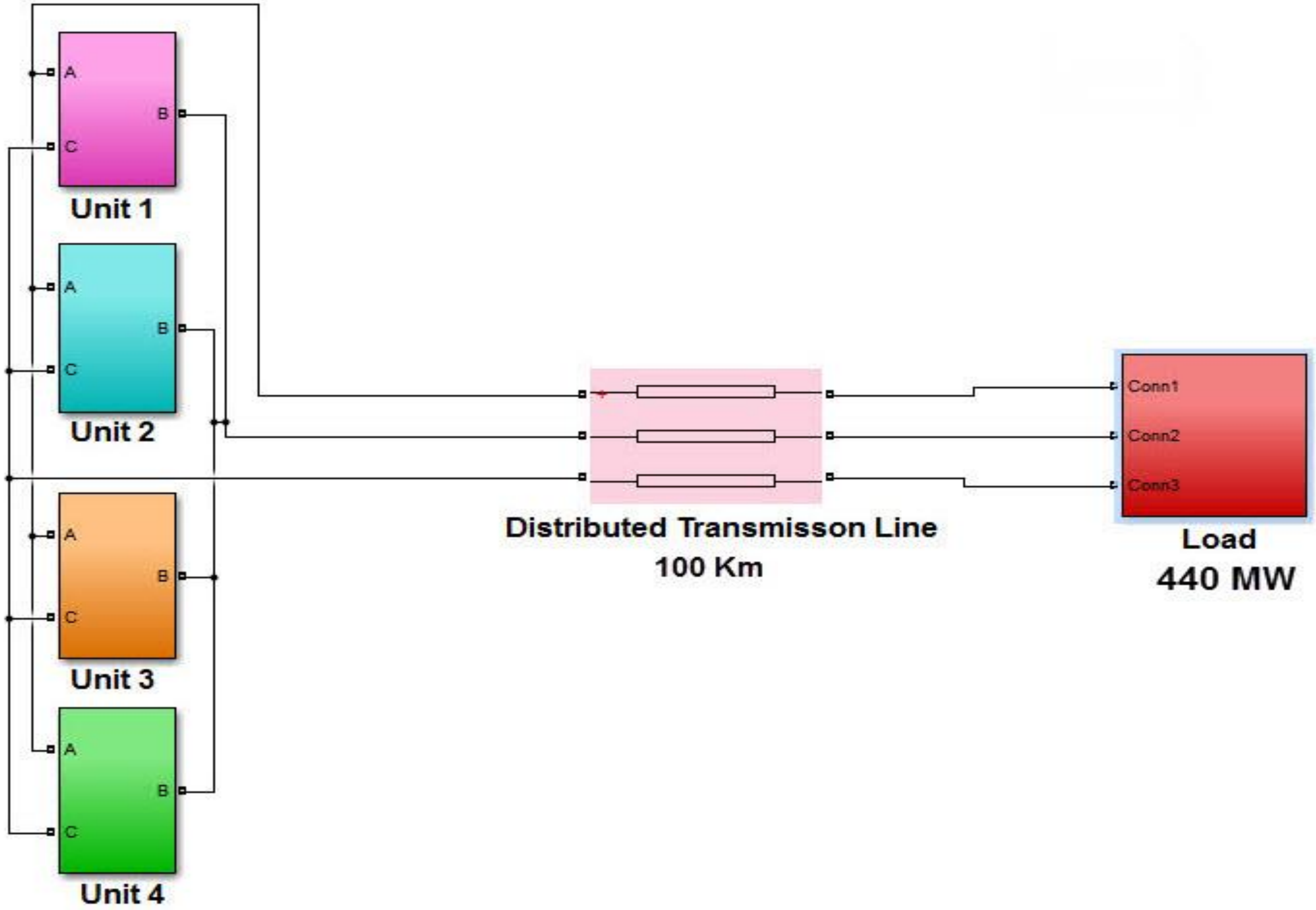

Figure 5.1 Model for four unit of BGPP.

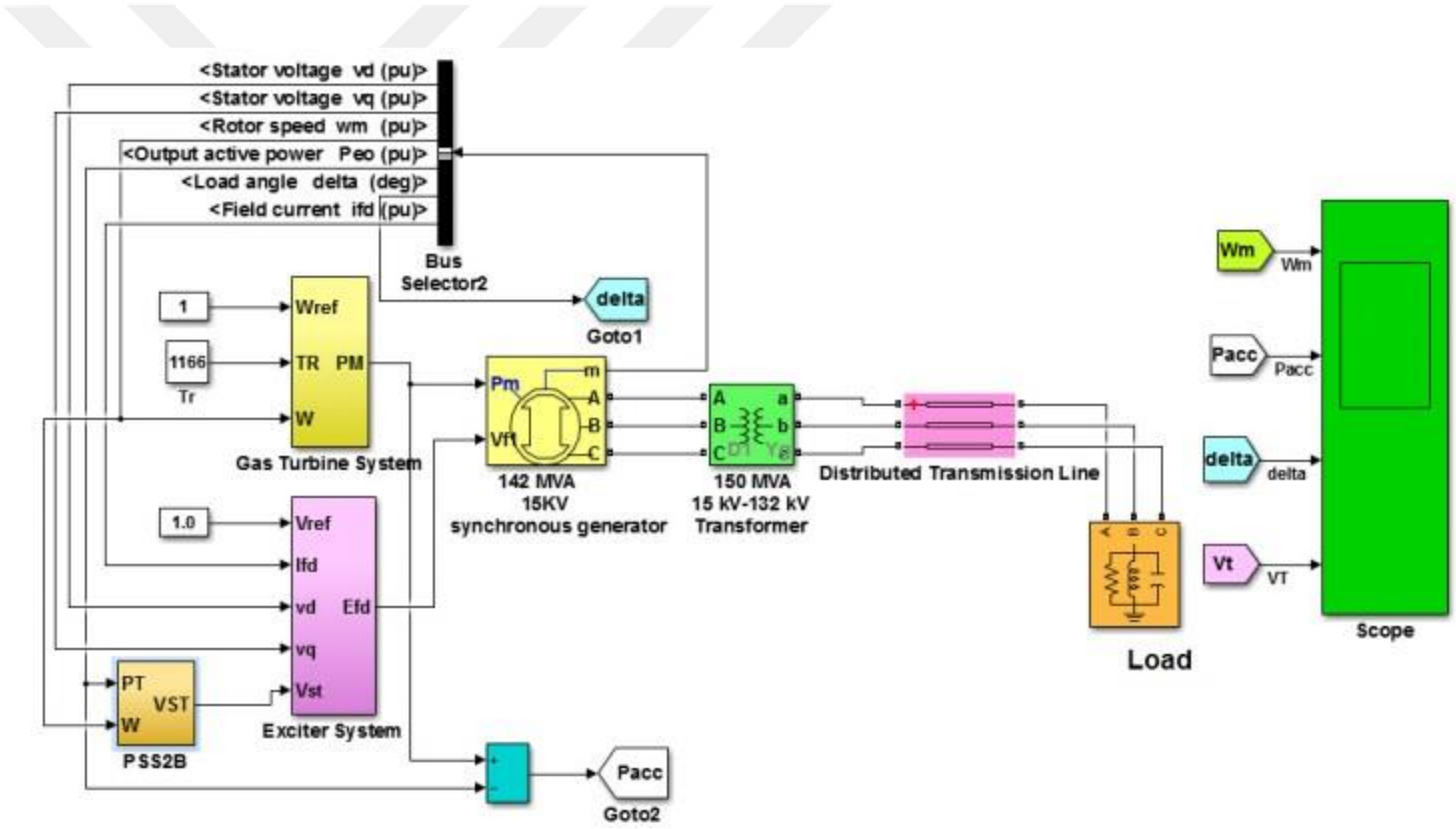

Figure 5.2 The model for one unit of BGPP

5.2.1 Case Study One:

In this case study, a small disturbance is applied to the rotor speed of BGPP. This is accomplished to the gas turbine governor. Reference step is changed by 5%. The system response under this small disturbance is appeared in Figure 5.3. It is visible that the rotor speed, rotor angle, and terminal voltage are increased by increasing rotor speed reference of 5% increase. The governor and exciter are able to return the system to the stable point.

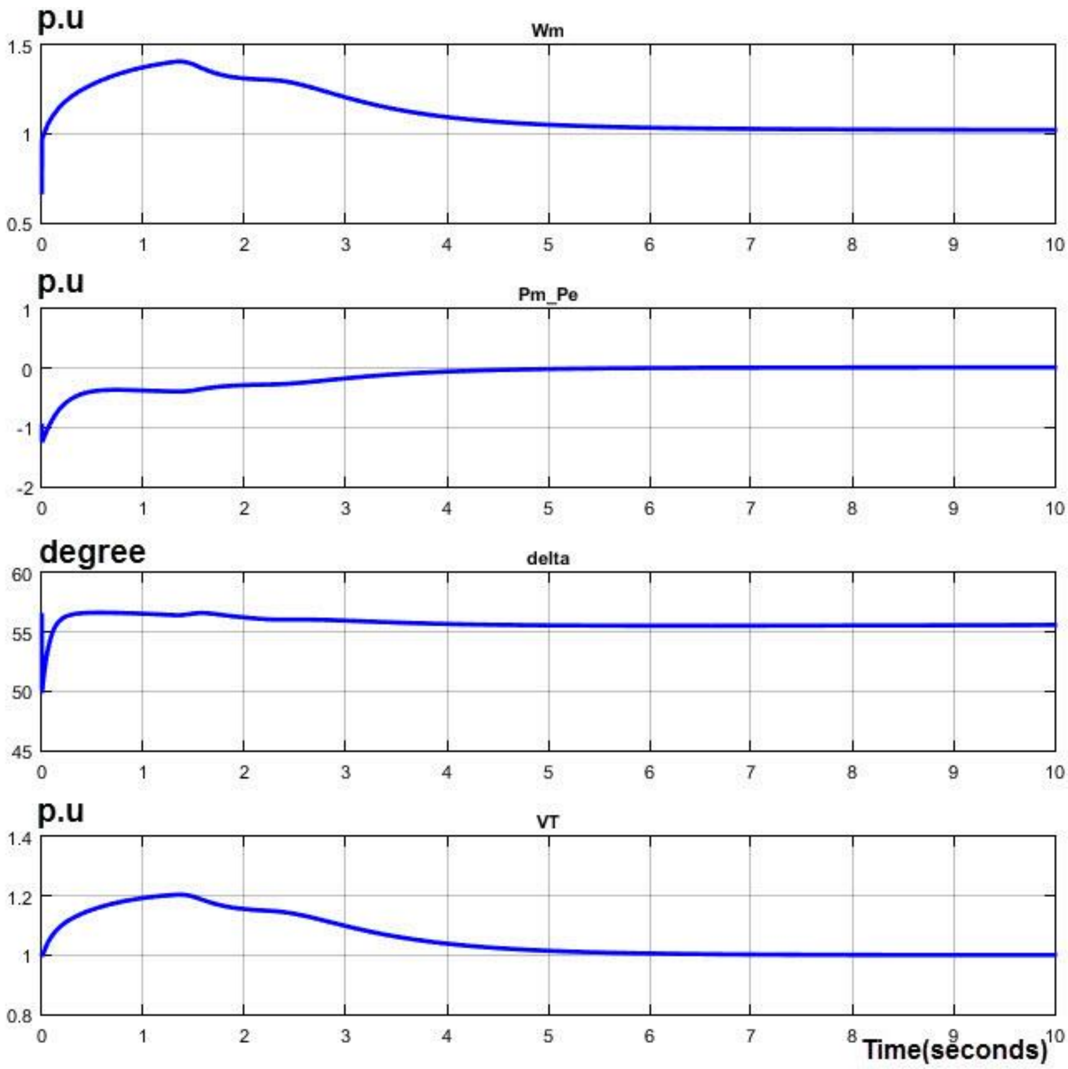

Figure 5.3 BGPP under small disturbance after speed step of +5%.

5.2.2 Case Study Two:

Single-phase fault is applied toward the end of the transmission line of BGPP at t=5s, the time fault duration is 0.2s and clarified at t=5.2s [42]. The system answer for this case is appeared in Figure 5.4. It is clear from the simulation comes about that the system has great dynamic characteristics and system variables reach to their values following after this transient.

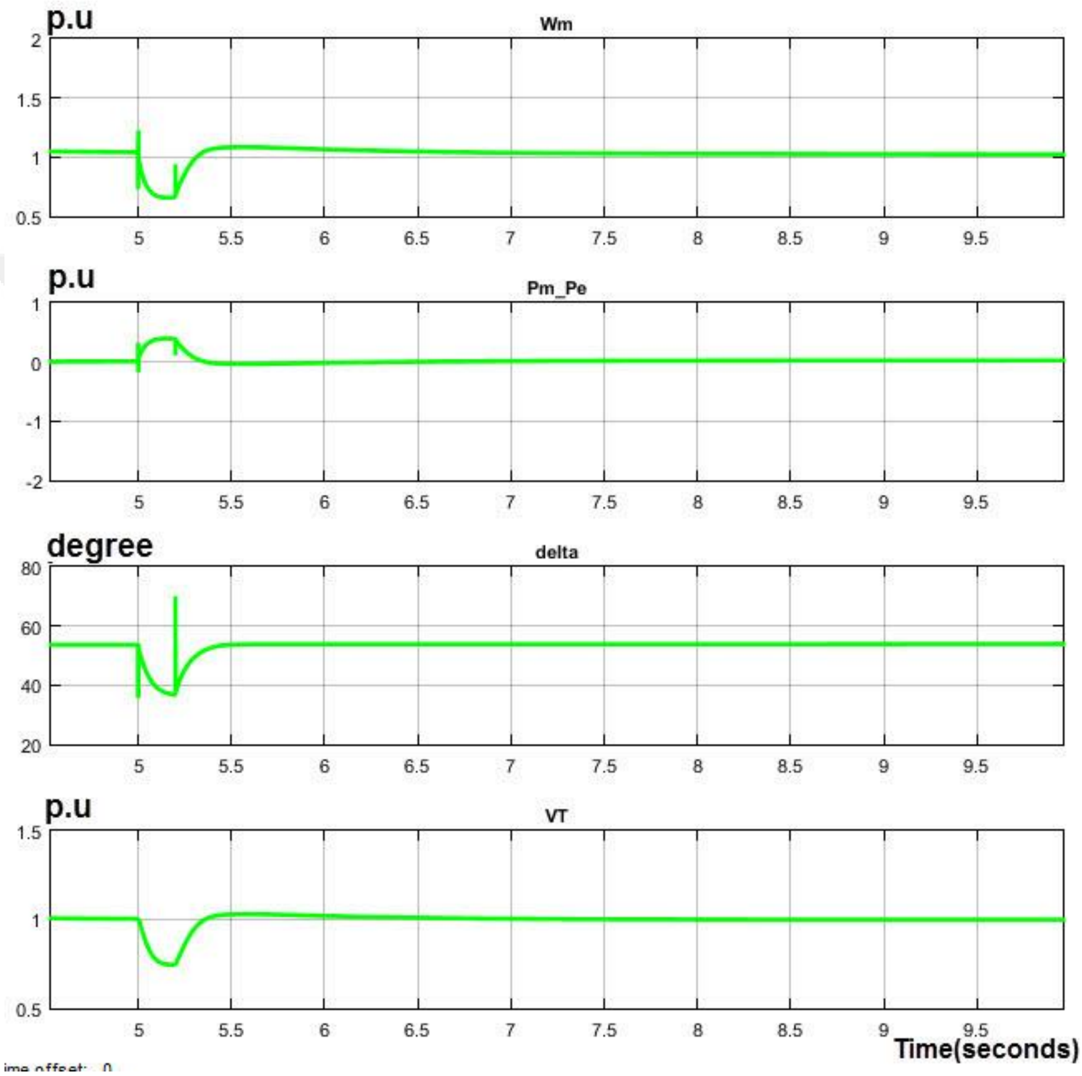

Figure 5.4 One phase fault at t=5s when connected at finish of transmission -line for BGPP.

5.2.3 Case Study Three:

In this case, a 3-phase fault is applied to the end of transmission-line (100 KM) for BGPP. The three-phase fault is initiated at t=5s and clarified at t=5.2s. The system response for this case study is shown in Figure 5.5. It is seen that the rotor speed is decreased to nearly zero so that the rotor angle (delta) also decreases to zero. The acceleration power (P_{acc}) increases to 1 pu, because of the fault, electric power output (P_e) is decreased to zero. The zoomed version of Figure (5.5) is shown in Figure (5.6). The station is able to restore equilibrium state after this disturbance.

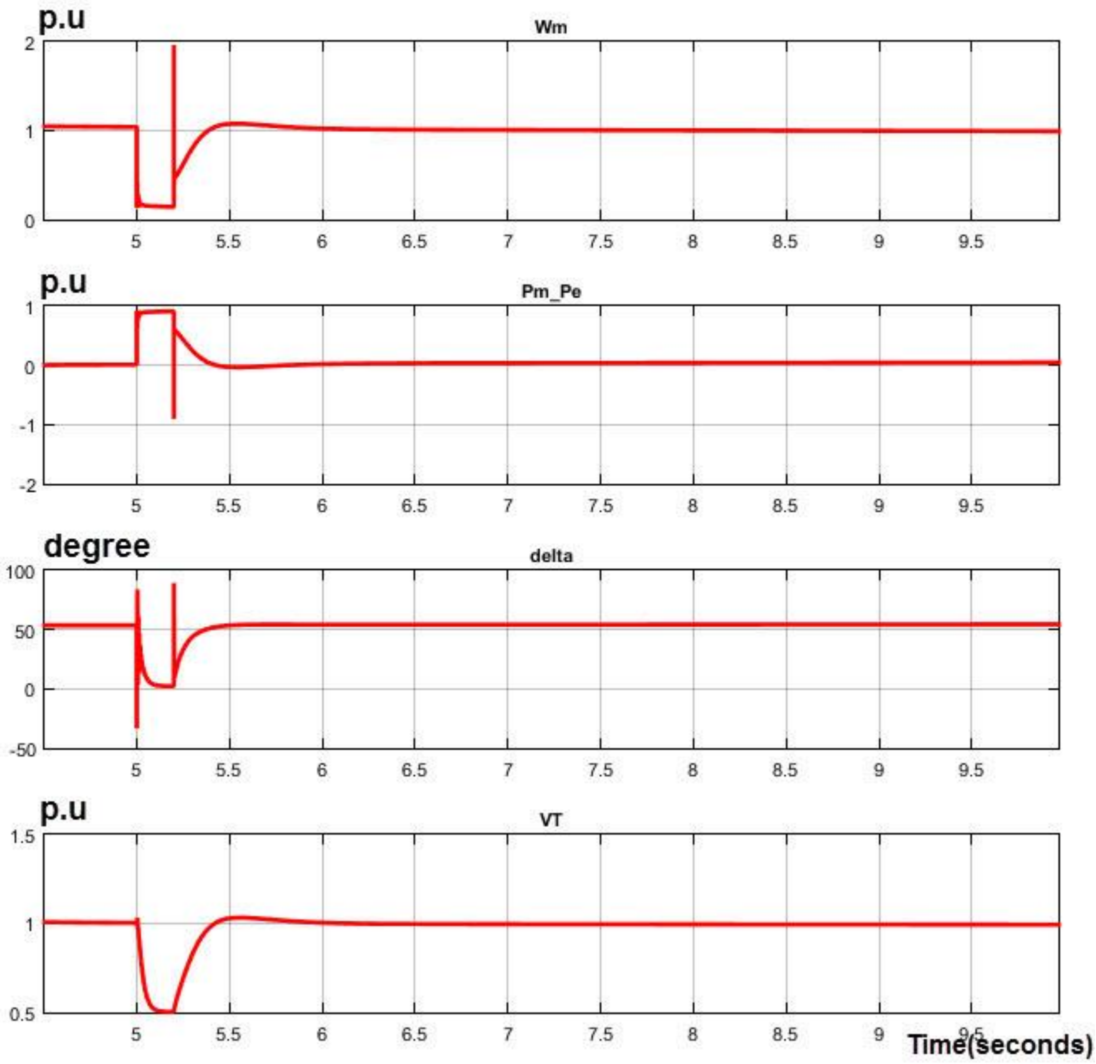

Figure 5.5 3-ph fault when t=5s at end of transmission line for BGPP.

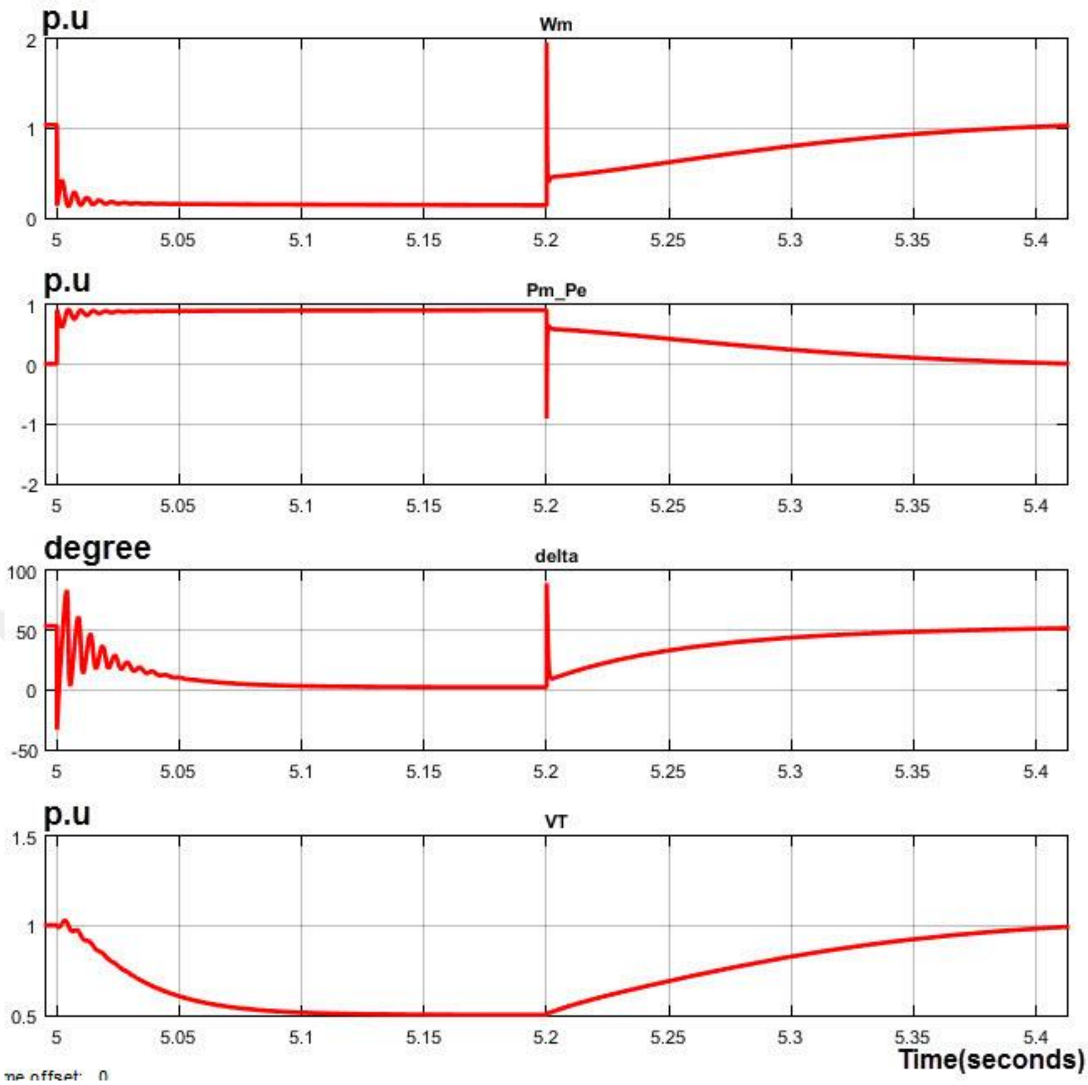

Figure 5.6 Zoom in the duration of 3-phase fault when connected at finish of transmission-line for BGPP in Fig. (5. 5).

5.2.4 Case Study Four:

Single-phase fault is applied at the midpoint of the transmission line (100 KM) of BGPP at t=5s. The system answer for this case is appeared in Figure 5.7. It is clear from the figure the single-phase fault of midpoint overhead transmission line that the rotor speed is decrease through time fault, when fault is disappeared the governor work to return the speed to first state 1p.u. Acceleration power is increase during the fault. When the fault is removing the acceleration control can restore acceleration power to stable state. The rotor angle (delta) is slaw down and then returns back to the first state. The terminal voltage is also decrease during the fault; after the fault terminal voltage is go to stable state.

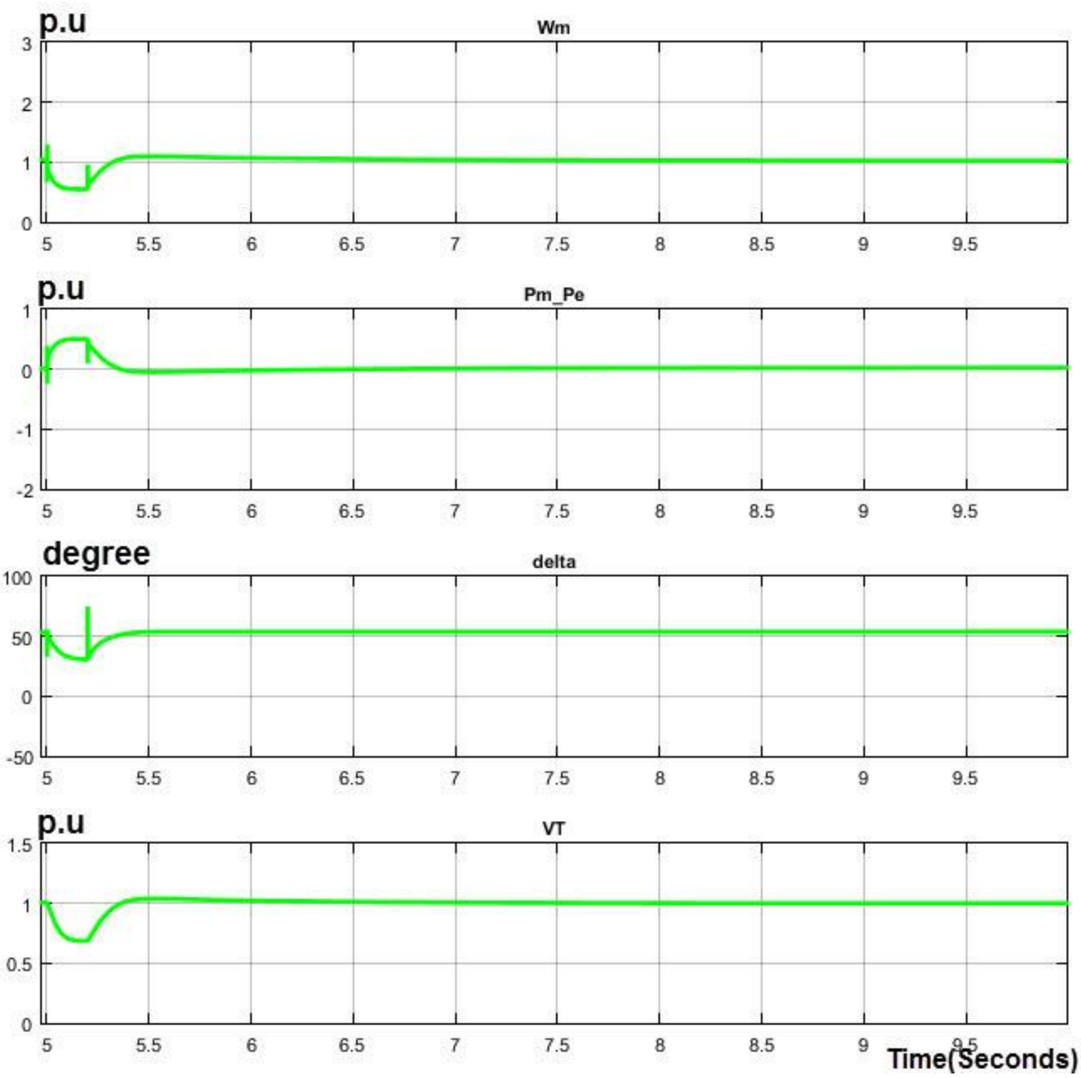

Figure 5.7 One phase fault at t=5s when applied at midpoint of transmission -line for BGPP

5.2.5 Case Study Five:

Three-phase fault is applied at the midpoint of the transmission line (100 KM) of BGPP at t=5s. The system answer for this case is appeared in Figure 5.8 and 5.9. It is clear from the figure of 3-phase fault of midpoint overhead transmission line that the rotor speed and the terminal voltage is decrease during time fault, when fault is disappeared the BGPPs controller work to return the speed and terminal voltage to original state. Acceleration power is increase through the fault. When the fault is removing the acceleration control can restore acceleration power to first state to zero. The rotor angle (delta) is delay to zero, and then return back to the original state.

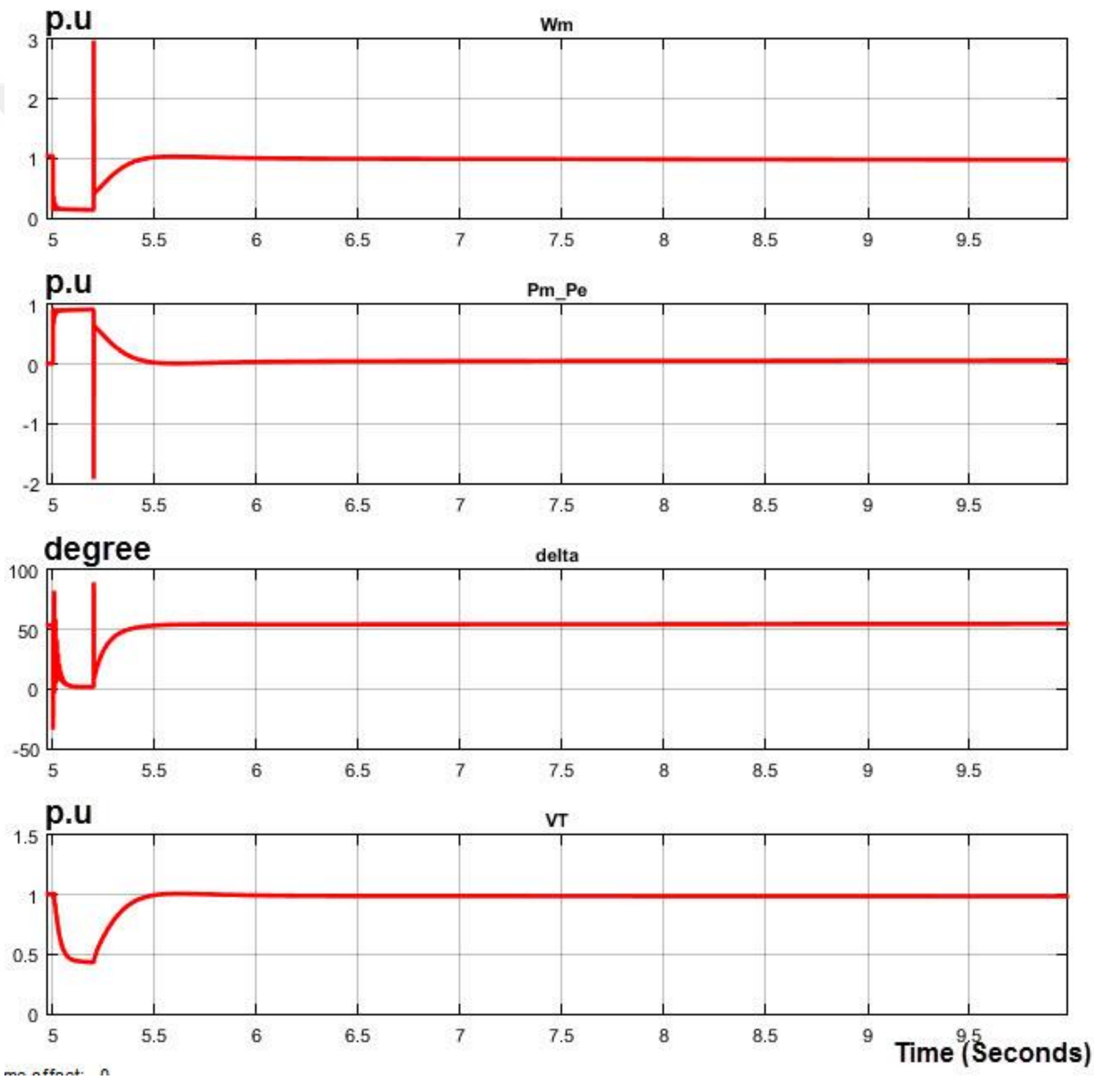

Figure 5.8 Tree-phase fault when t=5s at midpiont of transmission line (100KM) for BGPP

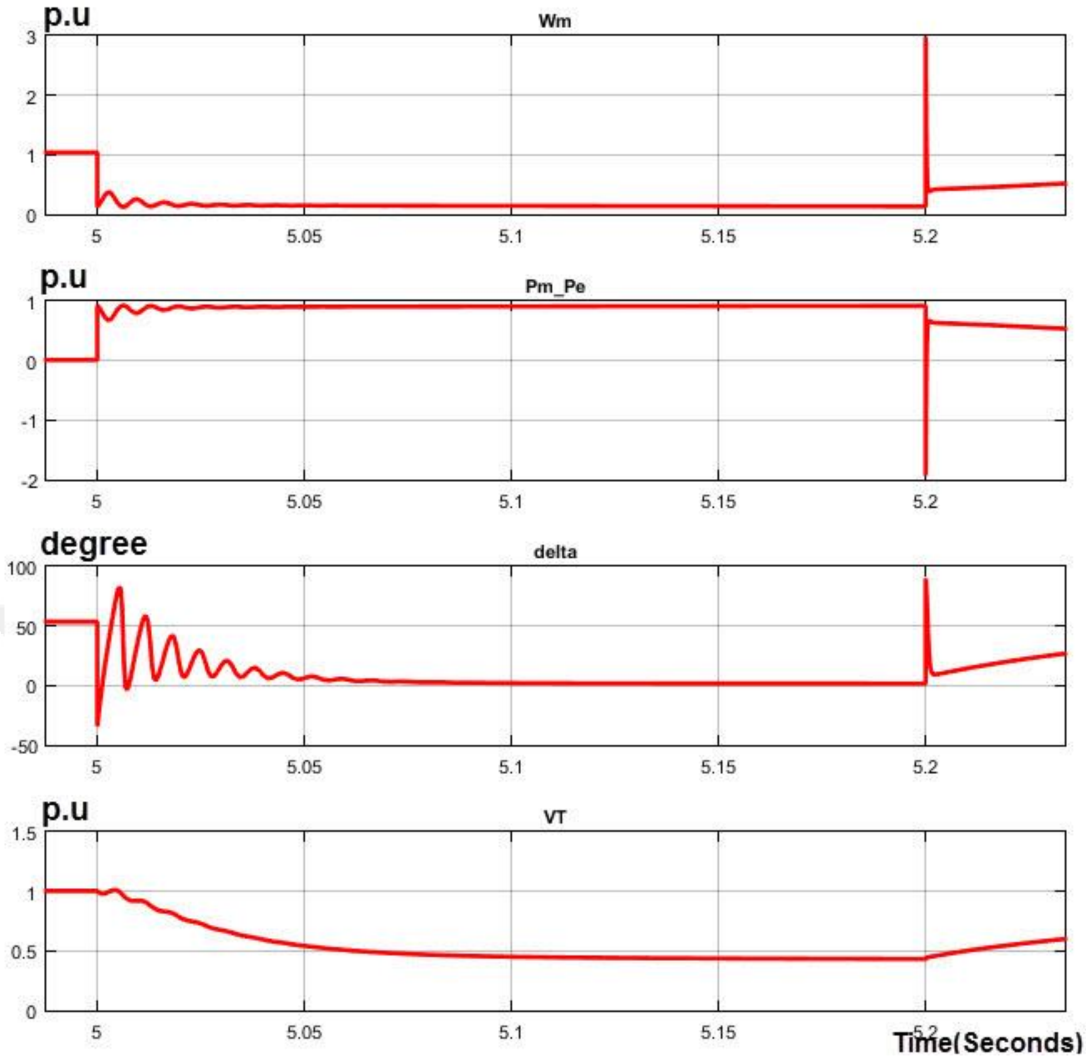

Figure 5.9 Zoom in the duration of 3-phase fault when connected at midpiont of transmission-line for BGPP in Figure (5. 8).

5.2.6 Case Study Six:

Single-phase fault is applied at the beginning of the transmission line of BGPP at t=5s. The system replay for this case is appeared in Figure 5.10. It is clear from the figure that the system at single-phase fault of beginning overhead transmission line that the rotor speed and terminal voltage is decrease and oscillated through time fault, when the fault is cut off the control section work to return the BGPP to original state. Acceleration power is increase during the fault. When the fault is removing the acceleration control can restore acceleration power to stable state to zero. The rotor angle (delta) is decrease and oscillation then return back to the first state.

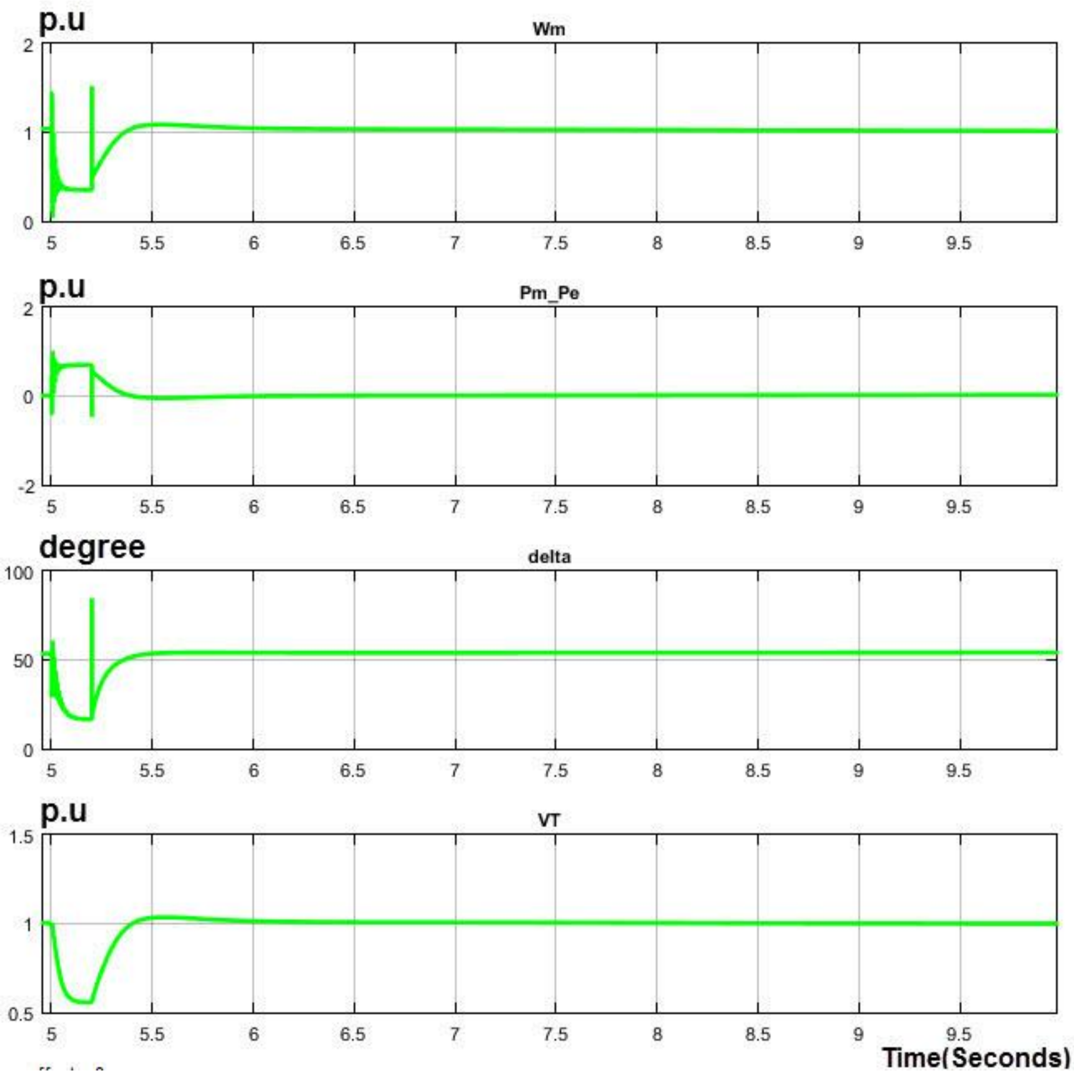

Figure 5.10 One phase fault at t=5s when connected at beginnig of transmission - line for BGPP

5.2.7 Case Study Seven:

At the beginning of the transmission line, three-phase fault is applied of BGPP at t=5s, the system answer for this case in Figure 5.11 and 5.12. It is clear from the figure of three-phase fault at beginning transmission line that the rotor speed and terminal voltage are decrease through the fault, when fault is remove the controller part work to return these to original state. Acceleration power is increase to during the fault. When the fault is removing the acceleration control can restore acceleration power to stable state to zero. The rotor angle (delta) is slaw down to zero and oscillation then return back to the first state.

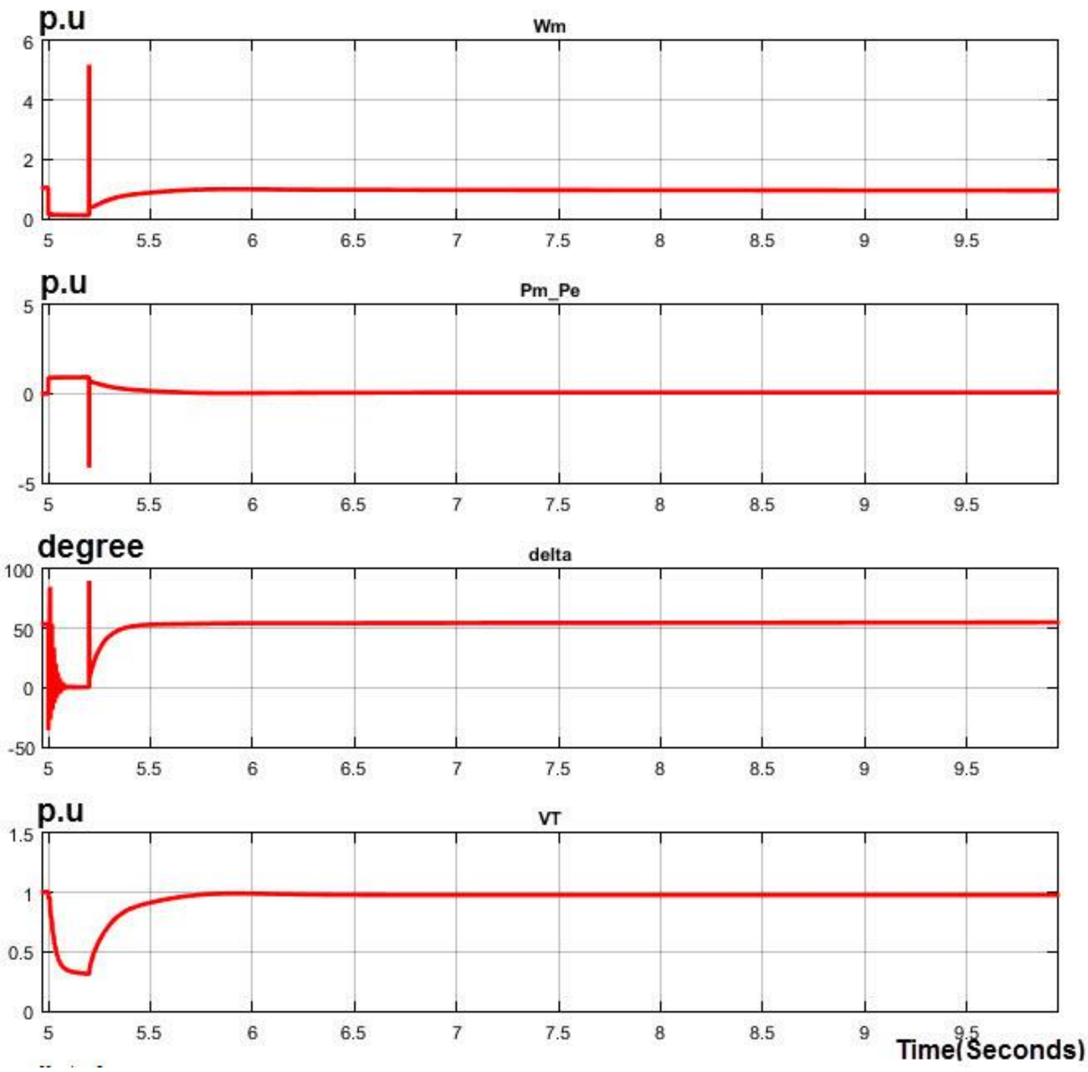

Figure 5.11 Three phase fault at t=5s when connected at beginnig of transmission - line for BGPP

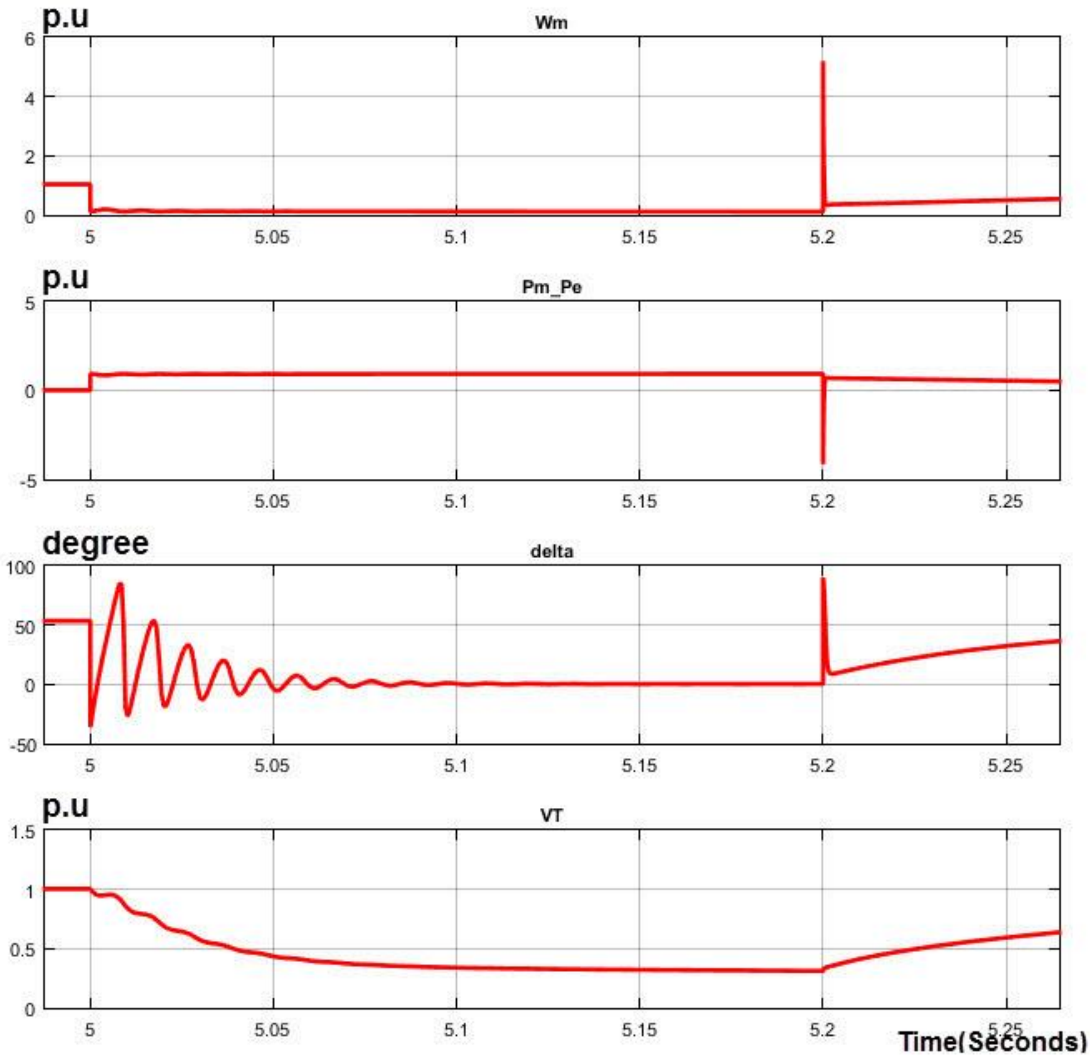

Figure 5.12 Zoom in the duration of 3-phase fault when connected at beginnig of transmission-line for BGPP in Fig.(5. 11)

5.3 Discussion Of The Results

BGPP is tested under three type faults (small disturbance, single phase fault and three phase fault) at four different positions (rotor speed, at beginning transmission line, midpoint transmission line and finish of transmission line). All cases are explained with there's a figure in above and we observe these points:

1. **Small disturbance:**

When small disturbance is applied to the rotor speed of BGPP (Reference step is increased by 5%), we see small oscillation in all parameters (speed control, acceleration control, rotor angle and terminal voltage) and the station can restore the first state and goes to stable region.

2. Single phase fault:

A. At beginning of the transmission line:

Single-phase fault is connected at the beginning of the transmission line of BGPP at t=5s is appeared in Figure 5.10. We can observe from the figure that the system at single-phase fault of beginning transmission line that the rotor speed is decrease to 0.4p.u and oscillated through time fault, when fault is disappeared the governor work to return the speed to original state 1p.u. Acceleration power is increase to 0.8p.u during the fault. When the fault is removing the acceleration control can restore acceleration power to equilibirum state. The rotor angle (delta) is slaw down to 20° and oscillation then return back to the first state. The terminal voltage is also decrease to 0.6p.u and oscillation during the fault, after the fault, terminal voltage is go to stable state.

B. At midpoint transmission line:

Single-phase fault is connected at the midpoint of the transmission line (100 KM) of BGPP at t=5s is appeared in Figure 5.7. It is clear from the figure that the single-phase fault of midpoint overhead transmission line, the rotor speed is decrease to 0.6p.u through time fault, when fault is disappeared the governor work to return the speed to original state 1p.u. Acceleration power is increase to 0.5p.u during the fault. When the fault is removing the acceleration control can restore acceleration power to stable state to zero. The rotor angle (delta) is slaw down to 30° and then return back to the first state. The terminal voltage is also decrease to 0.7p.u during the fault, after the fault terminal voltage is go to stable state.

C. At end of the transmission line:

Single-phase fault is connected at the finish of the transmission-line of BGPP at t=5s, the rotor speed is decrease to 0.7p.u then the terminal voltage is decrease to 0.75 pu also therefore the electrical power is decrease and acceleration power is increase to 0.4p.u. After the disturbance, the controller of the station (governor, exciter and PSS) can help the system to be stable.

3. Three phase fault:

A. At beginning of the transmission line:

Three-phase fault is connected at the beginning of the transmission line of BGPP at t=5s in Figure 5.11 and 5.12. It is clear from the figure of three-phase fault at beginning overhead transmission line that the rotor speed is decrease to 0.1p.u through the time fault, when fault is disappeared the governor work to return the speed to original state 1p.u. Acceleration power is increase to 2p.u during the fault. When the fault is removing the acceleration control can restore acceleration power to stable state to zero. The rotor angle (delta) is slaw down to zero and oscillation then return back to the first state. The terminal voltage is also decrease to point 0.35p.u during the fault and after the fault terminal voltage is goes to stable state.

B. At midpoint of the transmission line:

Three-phase fault is connected at the midpoint of the transmission line (100 KM) of BGPP at t=5s. The system answer for this case is appeared in Figure 5.8 and 5.9. It is clear from the figure of 3-phase fault of midpoint overhead transmission line that the rotor speed is decrease to 0.15p.u through time fault, when fault is disappeared the governor work to return the speed to original state 1p.u. Acceleration power is increase to 0.95p.u during the fault. When the fault is removing the acceleration control can restore acceleration power to stable state to zero. The rotor angle (delta) is slaw down to zero and then return back to the first state. The terminal voltage is also decrease to 0.47p.u during the fault, after the fault terminal voltage is go to stable state.

C. At end of the transmission line:

When 3-phase fault is connected to the end of transmission-line for BGPP (the 3-phase fault is initiated at t=5s and clarified at t=5.2s), the rotor speed is decrease to 0.2 pu then the terminal voltage is decrease to 0.5 pu also therefore the electrical power is decrease and acceleration power is increase to 0.9 pu. Controller system working to making the system is stable.

CHAPTER 6

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

This work presents the modeling and simulation of Bazyan Gas Power Plant in Iraq. The actual data for the system components are taken from manufactures' data sheets. The simulation results partially explain and give a rough conclusion about what happens to the Bazyan Gas Power Plant when different types of disturbances are occurred in the system. Furthermore the following comments are briefly pointed out:

1. When small disturbance is applied to the rotor speed of BGPP. This is accomplished to the gas turbine governor. Reference step is changed by 5%. The system response under this small disturbance is adequately ready to damp out low frequency oscillations after the disturbance. It means that the speed control and exciter and PSS are working well and protect the system.
2. The single-phase fault at the beginning of the transmission-line of BGPP at t=5s is more effective than other types of faults such as single-phase fault at the midpiont of the transmission-line and single-phase fault connected at the end of teh transmission-line. It is clear from the simulation results that the system has sufficient dynamic characteristics. This means that the station can restore its state to stable region and work at normal operation condition.
3. The power station when subjected to 3-phase fault at beginning of the transmission-line when initiated at t=5s and cleaned at t=5.2s is more effective and more dangerous than the other two cases such as 3-phase fault at the midpiont of the transmission-line and 3-phase fault at the end of the transmission-line. The system is able to restore its initial operating conditions when these faults are cleared in an acceptable amount of time. This means that the system controller (speed control, exciter system AC7B and PSS2B) are working good and also able to damp oscillations to restore the nominal operating conditions of the system.
4. This thesis can also serve as a background for the students who wants to know more about the details of the constructing blocks of the BGPP.

6.1 About Future Work

The installation of Gas Turbine Plants is continuing and increasing year by year. They are also combined with the steam turbines to produce combine (joined cycle) power station. A joined cycle control plant can be utilized as both a gas and a steam turbine together to create up to 50 percent more power from a similar fuel than a conventional basic cycle plant. The waste heat from the gas turbine is steered to the adjacent steam turbine, which creates additional power.

A Heat Recovery Steam Generator (HRSG) catches fumes warm from the gas turbine that would some way or another escape through the exhaust stack. The HRSG makes steam from the gas turbine fumes warmth and conveys it to the steam turbine, in this manner its segment are:

1) Gas Turbine: The gas turbine comprises of a compressor, combustor and turbine. The compressor packs the encompassing air; fuel, blended with compacted air, consumes in the combustor; and the high-temperature, high- pressure gas extends in the turbine.

2) HRSG (Heat Recovery Steam Generator): The fresh out of the plastic new warms triple-pressure HRSG for the 1300°C-class gas turbine can be demonstrated. The HRSG steam system reuses the vitality of fumes gas, and it responds to changes in gas turbine fumes stream and fumes temperature.

3) Steam Turbine: High pressure, transitional weight and low pressure steam turbines and a warm sort steam turbine are demonstrated. A speed senator system is considered for the steam turbine in multi-shaft sort consolidated cycle.

Our proposals for future work to BGPP are wide extended by making the plant from straightforward gas cycle to combine cycle to build the electrical power yield and effectiveness of a plant.

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APPENDIX

APPENDIX - A

SAMPLE DATA FOR A GAS TURBINE SYSTEM

Parameter	Description	Value	Unit
W	Gain = 1/ droop (pu MW / pu speed)	16.7	–
X	Speed Control lead time constant (s)	0.6	s
Y	Speed Control lag time constant (s)	1.0	s
Z	Speed Control mode (1=droop, 0=isochronous)	1	–
MAXIMUM	Request upper limit (pu)	1.5	pu
MINIMUM	Request lower limit (pu)	-0.1	pu
a	Valve positioner	1	–
b	Valve positioner time constant	0.05	s
c	Valve positioner	1	–
W_{min}	Minimum fuel inflow	0.23	–
T_f	Fuel time constant (s)	0.4	s
K_f	Fuel feedback system	0	–
E_{CR}	Combustion time delay (s)	0.01	s
E_{TD}	Turbine and exhaust delay time (s)	0.04	s
T_{CD}	Compressor discharge time constant (s)	0.2	s

T_R	Rated exhaust temperature (°F)	1166	°F
T_r	Reference Temperature rate (°F)	450	°F
f_1	TX=TR-700*(1-WF)+550*(1-N)		–
f_2	1.3*(WF-0.23)+0.5*(1-N)		–
T_1	Inertia = 2*H	13.9982	MWs/ MVA

APPENDIX - B

SAMPLE DATA FOR A TYPE AC7B EXCITER SYSTEM

Parameter	Description	Value
T_R	Terminal voltage transducer	0
X_C	Terminal voltage transducer	0
R_C	Terminal voltage transducer	0
K_c	Rectifier Commutation Factor	0.12
K_D	Load Factor	1.161
K_{DR}	AVR Derivative Gain	0.00
K_E	Alternator Gain	1.0
K_{F1}	Field Voltage Feedback Gain	0.0
K_{F2}	Field Current Feedback Gain	1.0
K_{F3}	Rate Feedback Gain	0.0
K_{1A}	FVR Integral Gain	2.028
K_{IR}	AVR Integral Gain	20
K_L	Lower Forcing Limit	10.0
K_P	Potential Forcing Term	31
K_{PA}	FVR Proportional Gain	2.028
K_{PR}	AVR Proportional Gain	20
T_{DR}	AVR Derivative Gain Filter	0.00
T_E	Exciter Time Constant	0.63
T_F	Rate Feedback Time Constant (Not used)	1.00
V_{Amax}	FVR Positive Limit	1.0
V_{Amin}	FVR Negative Limit	-0.99
$V_{Emax-E1}$	Maximum exciter EFD, pu	8.399
$V_{E0.75max-E2}$	75% Maximum exciter EFD, pu	6.3
$S_{Emax-SE1}$	Saturation Factor at Maximum EFD	0.142
$S_{E0.75max-SE2}$	Saturation Factor at 75% Maximum EFD	0.60

V_{Emin}	Exciter Field Current Lower Limit	0.0
V_{Emax}	Exciter Field Current Upper Limit	21
V_{Rmax}	AVR Positive Limit	9.7
V_{Rmin}	AVR Negative Limit	0.0

APPENDIX - C

SAMPLE DATA FOR A TYPE PSS2B

Parameter	Value	Unit
V_{IS1}	Speed	p.u.
V_{IS2}	PT	p.u.
V_{IS1MIN}	-10.000	p.u.
V_{IS1MAX}	10.000	p.u.
V_{IS2MIN}	-10.000	p.u.
V_{IS2MAX}	10.000	p.u.
T_{W1}	2.000	S
T_{W2}	2.000	S
T_{W3}	2.000	S
T_{W4}	(By Passed)	S
T_1	(0.2 default) To be tuned	S
T_2	(0.02 default) To be tuned	S
T_3	(0.2 default) To be tuned	S
T_4	(0.02 default) To be tuned	S
T_6	0.000	S
T_7	5.000	S
T_8	0.5 (5*T9)	S
T_9	0.1	S
T_{10}	(0 default) To be tuned	S
T_{11}	(0 default) To be tuned	S
K_{S1}	(20 default) To be tuned	-
K_{S2}	T7/(2*H)	-
M	5	-

N	1	-
K_{S3}	1	-
K_{STMAX}	0.1	p.u.
K_{STMIN}	-0.1	p.u.