IJAREEIE

e-ISSN: 2278-8875
p-ISSN: 2320-3765

International Journal of Advanced Research

in Electrical, Electronics and Instrumentation Engineering

Volume 10, Issue 10, October 2021

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 7.282

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (IJAREEIE)

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 10, Issue 10, October 2021 ||

DOI:10.15662/IJAREEIE.2021.1010003 |

Control of Gas Turbine Speed Using Modelica

Mustafa Emhemed Abofares[1], N. M. Elasager[2]

Department of Electrical Engineering, Higher Institute of Engineering Technology, Ben Walid, Libya [1]

Department of Electrical Engineering, Faculty of Technical Sciences, Ben Walid, Libya[2]

ABSTRACT:In this study, speed control system has been designed for the heavy-duty gas turbine. The speed control includes three control loops: acceleration control - speed control -temperature control. Acceleration control determines the speed during the initial start-up period. Then, the speed/load controller is selected by a minimum selector to control the speed of the gas turbines. When the load increases, the torque increases and the speed decreases, the fuel should be increase to maintain the speed of the turbine at requires system. In this study, the gas turbine speed control system was modelled using Modelica and a Proportional-Integral-Derivative (PID) controller was designed to improve system performance.

KEYWORDS: Gas Turbine,ThermoPower,PID Controller, Modelica language.

I.INTRODUCTION

Gas turbines (GT) are one of the significant parts of modern industry. They play a key role in aeronautical industry, power generation, and in mechanical drivers for large pumps and compressors. Modelling and simulation of gas turbines have always been a powerful tool for performance optimization of this kind of equipment. Remarkable research activities have been carried out in this field and varieties of analytical and experimental models have been built so far to get in-depth understanding of the nonlinear behavior and complex dynamics of these systems [1].
However, the need to develop accurate and reliable models of gas turbines for different objectives and applications has been a strong motivation for researchers to continue to work in this fascinating area of research. Besides, because of the high demand of the electricity market, the power producers are eager to continuously investigate new methods of optimization for design, manufacturing, control and maintenance of gas turbines [2].

II. SIMULATION ENVIRONMENT

Modelica is an equation based object oriented modeling language where the focus on reusing component and model libraries are applied. In an equation based language the relationships between variables are specified by the user simultaneously and the causality is left open. An open causality means that the order to calculate the variables does not have to be specified by the user. Another advantage with the Modelica language is the concept of multi-domain modeling which means that different kinds of physical domains can be encapsulated in the same model [4]. In the available simulation platform, the considered domains are; the thermodynamic, the mechanical, and the electrical domain. In Modelica, state equations and algebraic constraints can be mixed which results in a model that is in a differential algebraic equation (DAE) form. For a differential algebraic equation model, the DAE-index of the model is an important property [6]. For simulation purposes, a state-space form of the system model is desirable and the DAE index is one measure of how easy/hard it is to obtain a state-space form. In general, higher index problems are often more complicated than lower index problems to simulate. Simulations of DAE-system are well described in Haireretal. (1991).For a comprehensive description of the Modelica language, see the language specification at the webpage in Modelica Association (2007), or the textbooks by Fritzson (2004); Tiller (2001)[8]. In Casella et al. (2006),the Medialibrary available in the standard Modelica package is presented. The available simulation platform consists of a controller, a fuel system, a starter motor, a transmission, and a single shaft gas turbine. The simulation platform and its components are shown in Fig 1. All of these components are written in the modeling language Modelica [9].The experimental platform can be used for start/stop trip simulations, and other dynamic and static operational cases.
During the simulation, environment conditions such as pressure, temperature, and relative humidity of the incoming air can be varied.

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 10, Issue 10, October 2021 ||

DOI:10.15662/IJAREEIE.2021.1010003 |

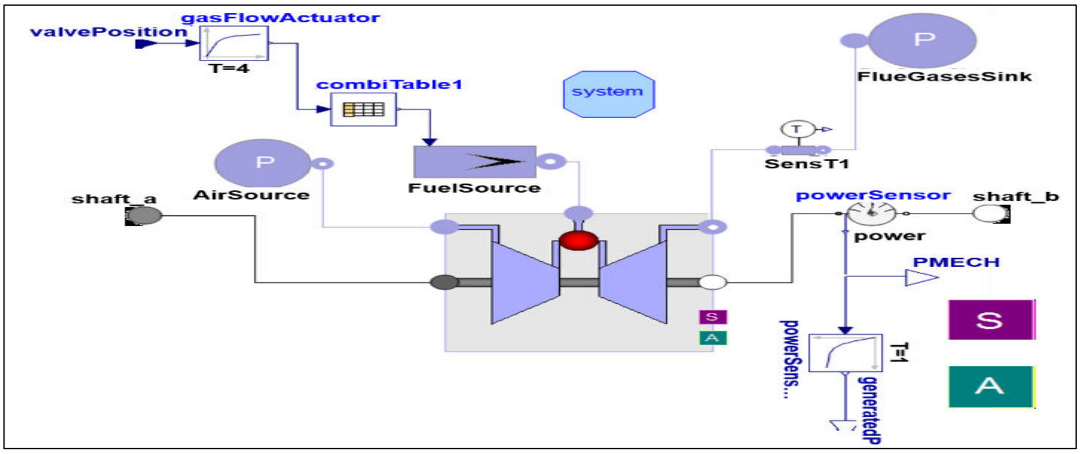


Fig. 1: The simulation platform

The advantage with the simulation platform is the ability to evaluate reliable performance estimation of parameters throughout the gas path, due to different operational conditions. The input signals to the simulation platform are the ambient pressure, the ambient temperature, the relative humidity of ambient air, and the desired generator power. In the simulation platform, the speed of the power turbine is fixed since here the application is a 50Hz electrical generator. It is easy to modify the platform to also handle variable speed of the power turbine.

III. DESIGN OF GAS TURBINE SPEED CONTROL SYSTEM

Rowen [7] has developed the transfer function block diagram is shown in Fig 2 of heavyand time constant by test and actual field experience accumulated from numerous installationsin many different applications. In dynamic analysis of combined cycle plants, twin shaft gasturbine model, combustion turbine model and biomass - based gas turbine plant and even inturbine power generation this transfer function model has been used. Basically, Rowen'smodel has speed, temperature and acceleration controllers.

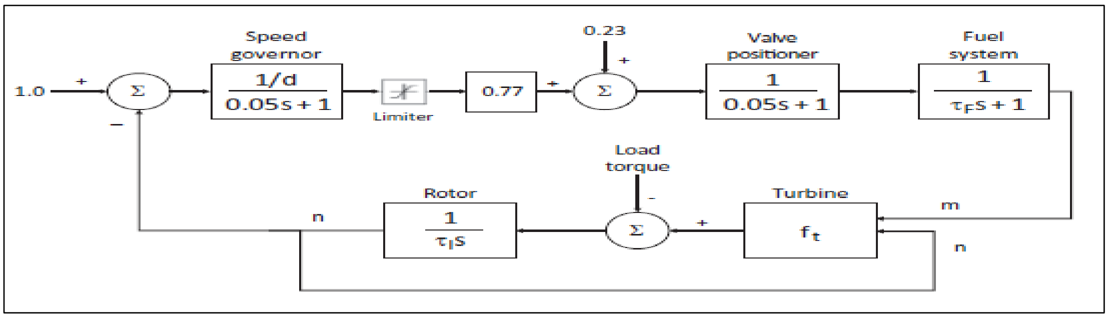


Fig.2: Transfer function model of gas turbine plant

- **Mathematical Model for Gas Turbine Speed Control**

The model of gas turbine speed control is shown in Fig 3, consists of three control loops:speed control -temperature control -acceleration control. The speed control is the main controlloop during normal operating conditions. The temperature and acceleration control are activein the case of abnormal operating conditions. The output of the three control loops are theinput to a minimum value gate so that the loop which takes control is the one which output isthe lowest of the three. The output of minimum value gate commands the fuel system andtherefore the mechanical power delivered by the gas turbine [8].

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (IJAREEIE)

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 10, Issue 10, October 2021 ||

DOI:10.15662/IJAREEIE.2021.1010003 |

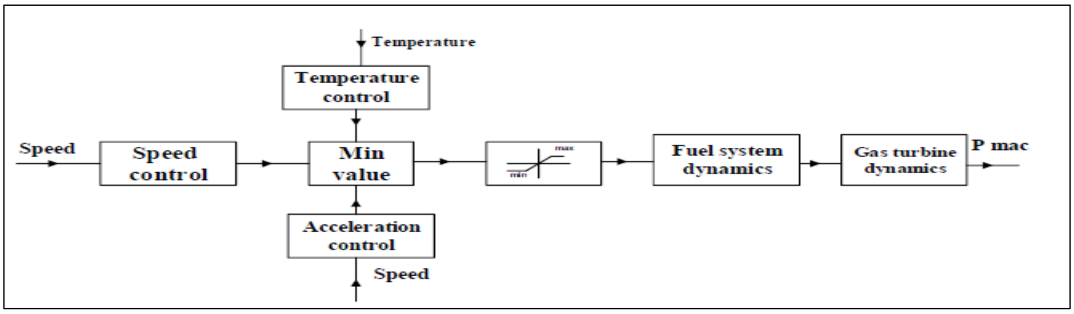


Fig 3: Modal of gas turbine speed control

- **System Design Using PID Controller**

PID controller is predominantly used for industrial control due to its ease of operation. The actual speed is compared with a reference and the error signal is applied to PID controller, PID controller settles the speed exactly at rated value with less oscillation and at a faster rate. The governor PID setting is shown in Table 1.

Table (1): The governor PID settings

P	I	D
3.7	1.07	1.9

Gas turbine speed control simulation using PID controller is shown in Figure 8.

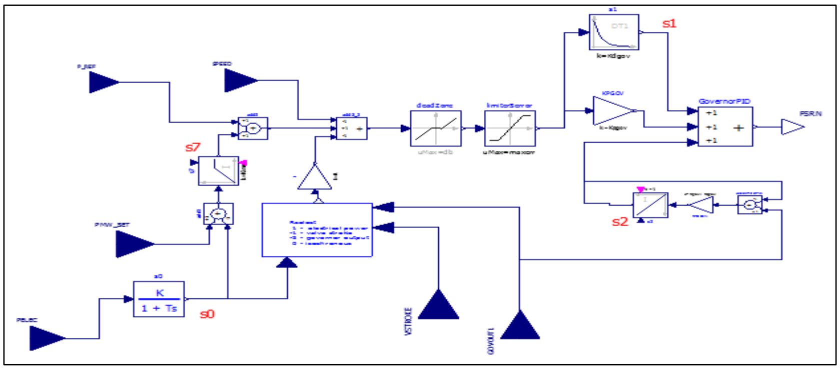


Fig 8: Gas turbine speed control simulation using PID controller

IV. SYSTEM SIMULATION RESULTS AND DISCUSSIONS

A mathematical model of the gas turbine as explained in chapter three is modelled with Modelica. Speed reference was kept constant at 1 $p.u.$ for all simulations.

a) System Simulation Results without PID Controller

The response of the developed gas turbine is given in the following simulation results:

- **Mechanical power**

Initially the gas turbine is operated at no-load. After that the gas turbine is loaded with variableload. The mechanical power of gas turbine response is shown in Fig 9.

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 10, Issue 10, October 2021 ||

DOI:10.15662/IJAREEIE.2021.1010003 |

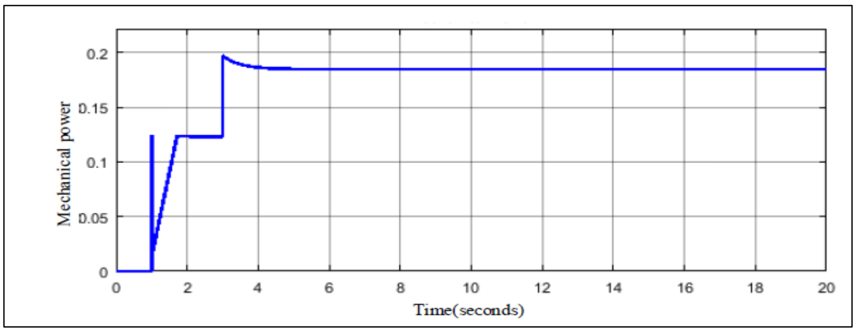


Fig 9: Mechanical power

- **Fuel demand**

The fuel demand at no load it is 23% (0.23 p. u). The load is applied to the gas turbine,which rises linearly from zero power at 23% fuel rate to the rated output at 100% fuel rate,increasing the amount of fuel required to keep the combustion process alive. The fuel demandof gas turbine response is shown in Fig 10.

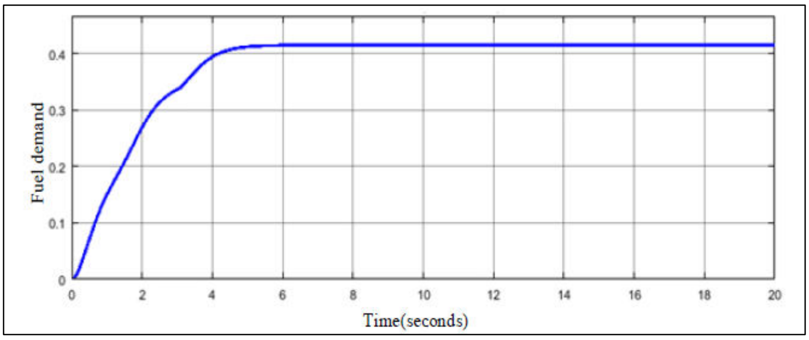


Fig 10: Fuel demand

- **Per unit speed - load**

Speed/load controller is double variable controller, before connect to load, speed/loadcontroller only speed after connect to load it will shaft to load control. Initial rate of speedchange is maintained after removal of rated load torque. The speed is compared with thereference speed and the error is given to the speed governor. The per unit speed (loadvariation) of gas turbine response is shown in Fig 11.

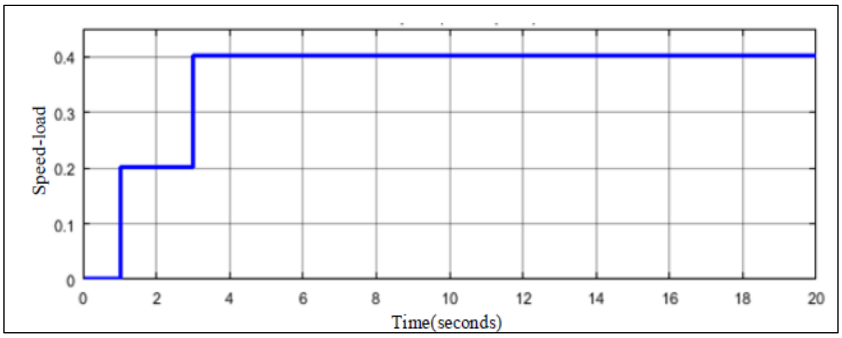


Fig 11: Per unit speed (load variation)

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 10, Issue 10, October 2021 ||

DOI:10.15662/IJAREEIE.2021.1010003 |

- **Turbine torque**

The torque characteristics of gas turbine are essentially linear with respect to fuel flow andturbine speed, the generator torque is the same as the shaft torque which produced by turbineat steady- state. The turbine torque of gas turbine response is shown in Fig 12.

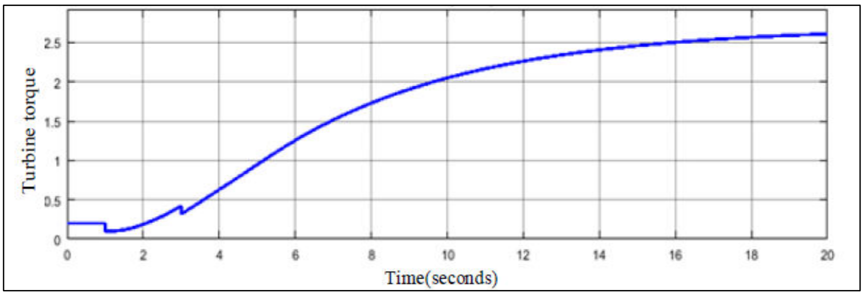


Fig 12: Turbine torque

- **Rotor speed**

When the gas turbine is operated at no-load, the speed of the rotor is equal to 10 p. u. and thestator line voltage of the generator reaches no-load steady-state value of 10. p. u. When thegenerator is loaded the voltage decreases from no-load value to 5 p. u. The rotor speed of gasturbine response is show in Fig 13.

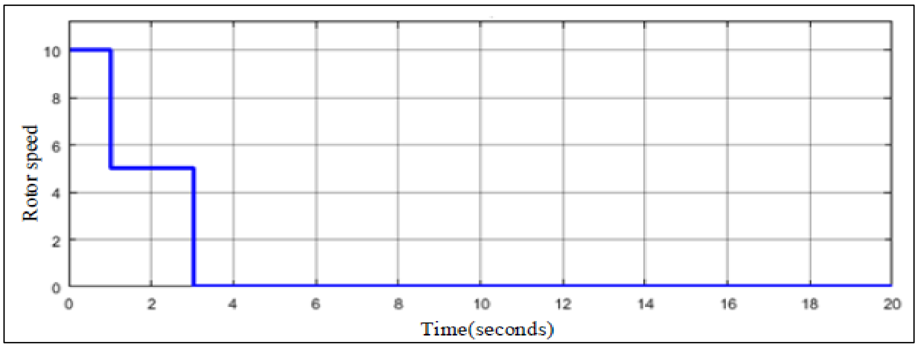


Fig 13: Rotor speed

- **Fuel demand and load**

The fuel demand and load are compared is shown in Fig 14.

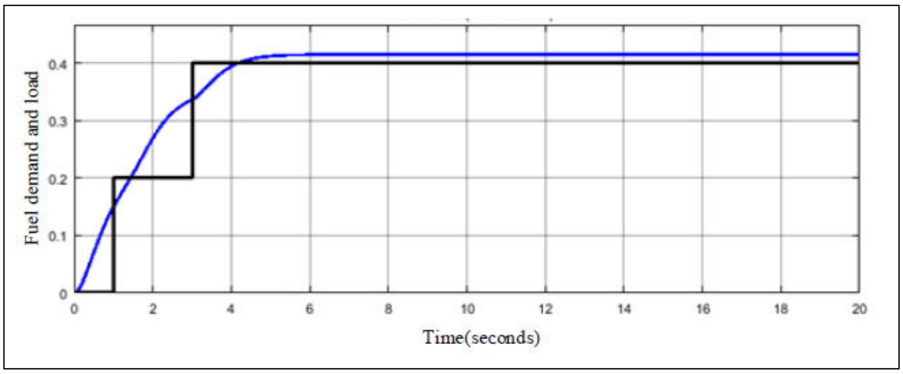


Fig 14: Fuel demand and rotor speed

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 10, Issue 10, October 2021 ||

DOI:10.15662/IJAREEIE.2021.1010003 |

b) System Simulation Results with PID Controller

The response of the improved gas turbine using PID controller is given in the followingsimulation results:

- **Mechanical power**

The mechanical power of the gas turbine controlled with PID controller is shown in Fig 15.

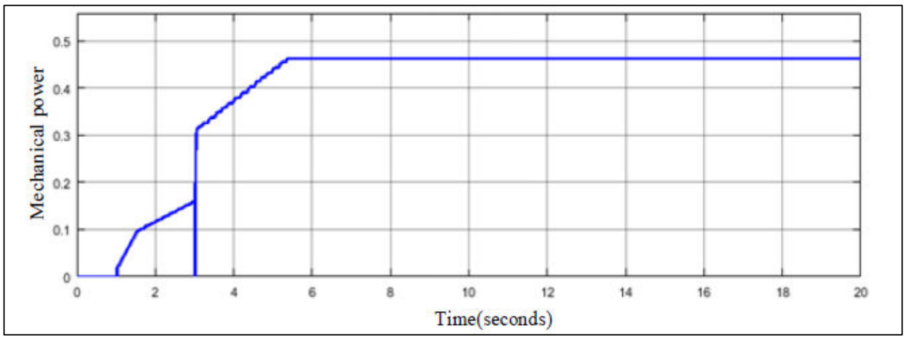


Fig 15: Mechanical power

- **Fuel demand**

The fuel demand of the gas turbine controlled with PID controller is shown in Fig 16.

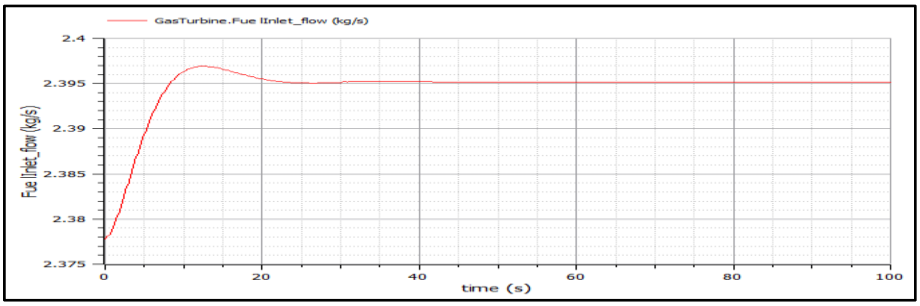


Fig 16: Fuel demand

- **Per-unit speed (load variation)**

The per unit speed (load variation) of the gas turbine controlled with PID controller is shown in Fig 17.

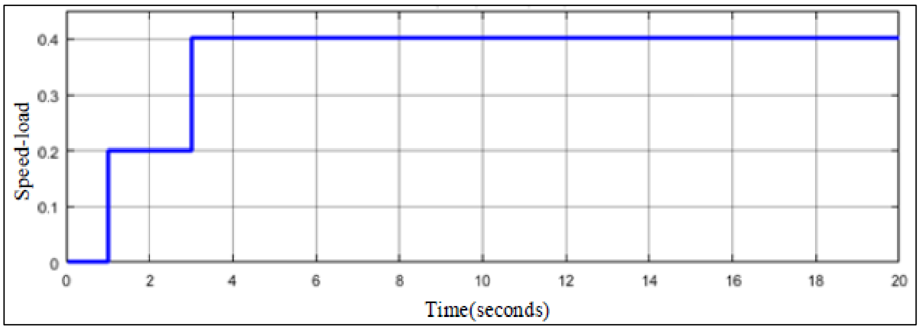


Fig 17: Per unit speed (load variation)

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 10, Issue 10, October 2021 ||

DOI:10.15662/IJAREEIE.2021.1010003 |

- **Turbine torque**

The turbine torque of the gas turbine controlled with PID controller is shown in Fig 18.

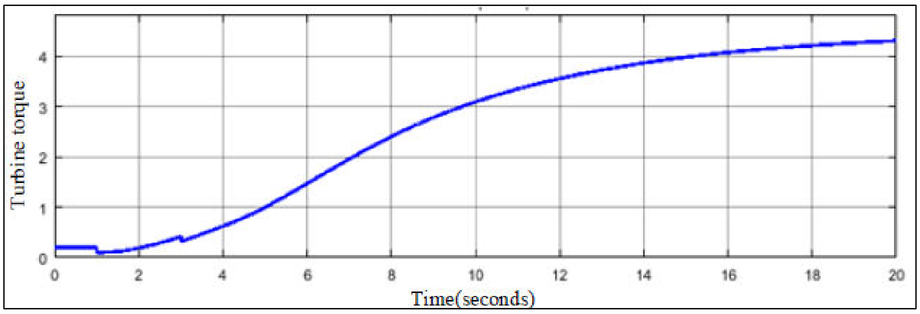


Fig 18:Turbine torque

- **Rotor speed**

The rotor speed of the gas turbine controlled with PID controller is shown in Fig 19.

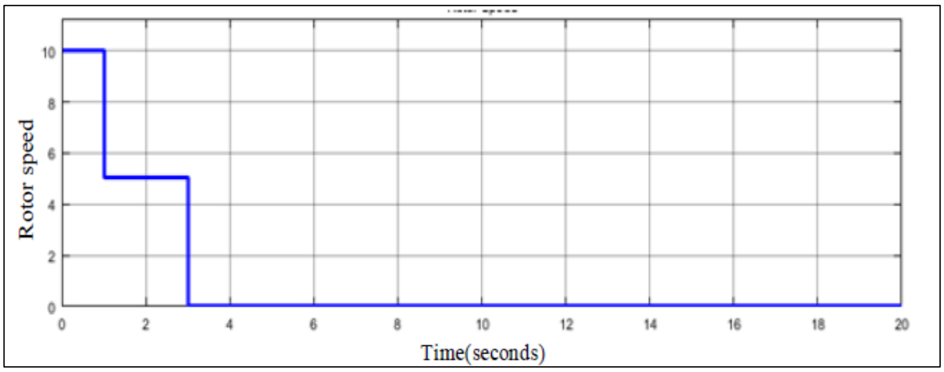


Fig 19: Rotor speed

- **Fuel demand and load**

The fuel demand and load after of the gas turbine controlled with controller is shown in Fig 20.

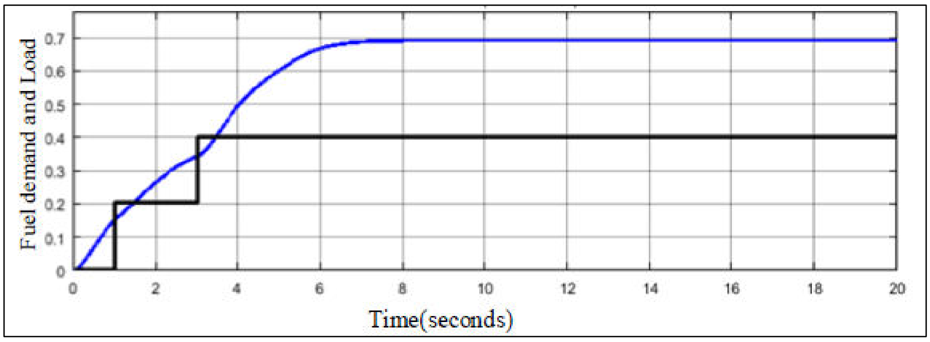


Fig 20: Fuel demand and load

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 10, Issue 10, October 2021 ||

DOI:10.15662/IJAREEIE.2021.1010003 |

- **Compare fuel and load variation**

The compare between fuel without PID controller and fuel of the gas turbine controlled withPID controller and load variation is shown in Fig 21.

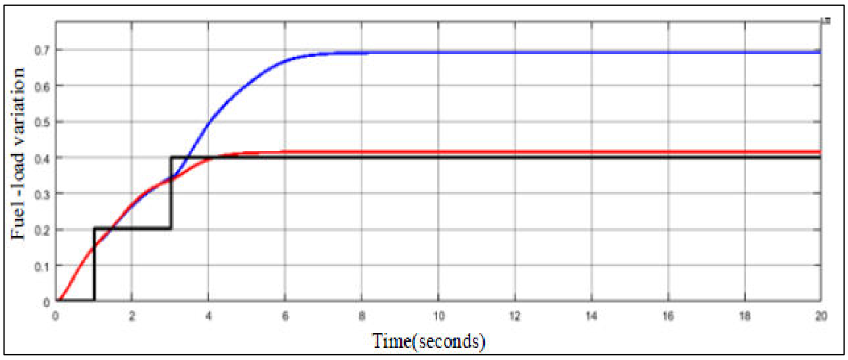


Fig 21: Compare fuel and load variation

- **Discussions**

The model of a single - shaft gas turbine system is suitable for power management, and thespeed control loop is necessary for the system stability. Low value selection plays a majorrole in the response of the model. The turbine torque increased with load and the rotor speeddecreased, the variation of load results in changing the speed which should by controlled beincreasing or decreasing the amount of inlet fuel. The system with PID controller improvesthe fuel valve time response.

V. CONCLUSION

In this study the gas turbine speed control system has been designed, the model is good for power generation. Detailed mathematical modelling of the control systems of the gas turbine is given and simulation of the developed gas turbine system model is carried out. The simulation results show that the developed model of the gas turbine system has the ability to meet the power requirements of the load.
Modelica is a suitable tool for building an object-oriented gas turbine. The simulations are very fast considering the number of math operations within the large model. This work provides proof of concept about Modelica employing complex power sources for co-modelling without the information loss that traditional network methods incur.

REFERENCES

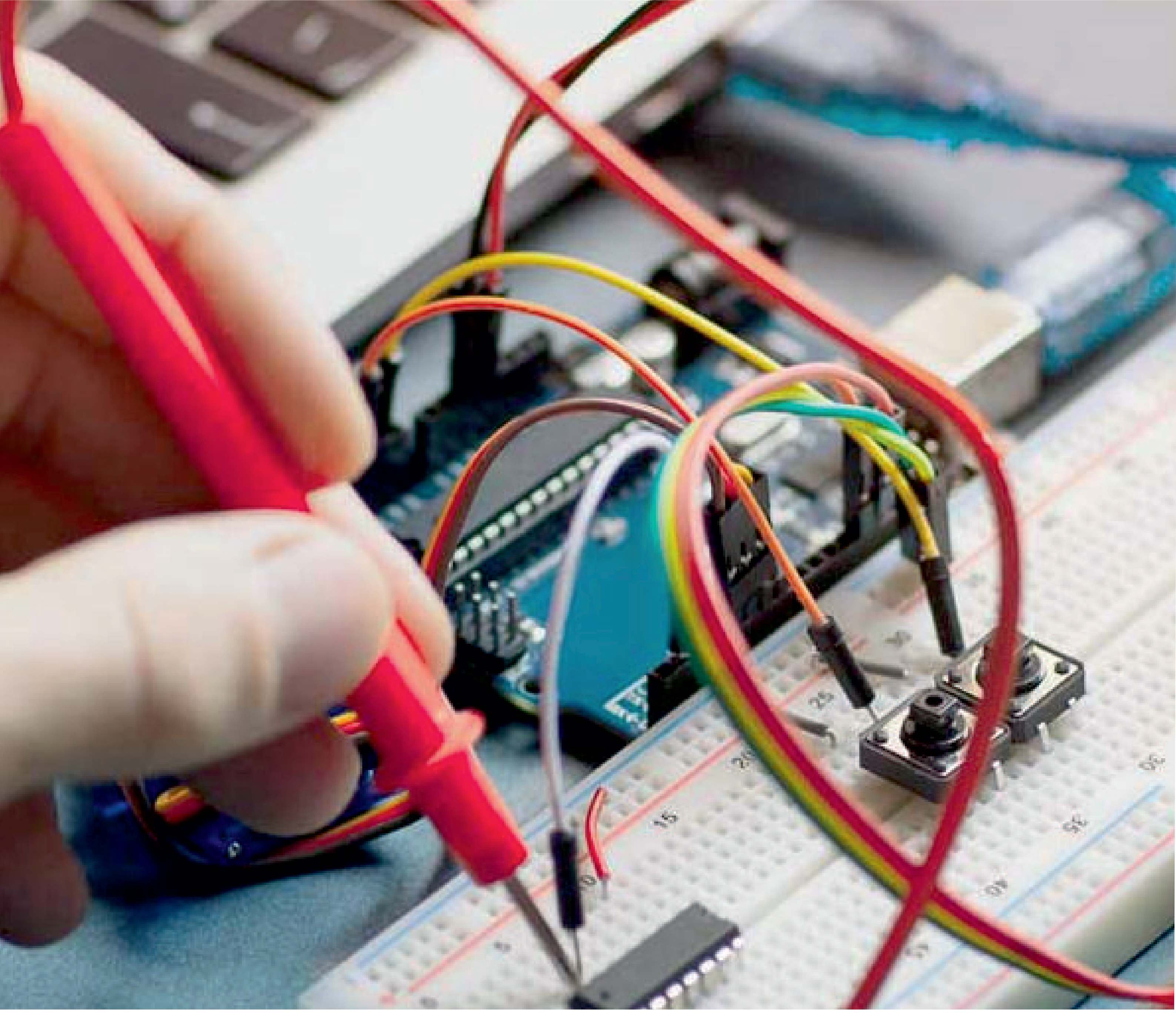
[1] Kim J, Garcia H. Nuclear-Renewable Hybrid Energy System for Reverse Osmosis Desalination Process.Transactions of the American Nuclear Society. 2015;112:121-4.
[2] Kim JS, Chen J, Garcia HE. Modeling, control, and dynamic performance analysis of a reverse osmosis desalination plant integrated within hybrid energy systems. Energy. 2016;112:52-66.
[3] Garcia HE, Chen J, Kim JS, McKellar MG, Deason WR, Vilim RB, et al. Nuclear Hybrid Energy Systems - Regional Studies: West Texas &Northeastern Arizona. Idaho Falls (ID): Idaho National Laboratory, NuclearScience and Technology Division; 2015 Apr. Report No.:INL/EXT-15-34503. Contract No.:DE-AC07-05ID14517. Sponsored by the U.S. Department of Energy.
[4] Garcia HE, Chen J, Kim JS, Vilim RB, Binder WR, Bragg Sitton SM, et al. Dynamic performance analysis of tworegional Nuclear Hybrid Energy Systems. Energy. 2016;107:234-58.
[5]Chen J, Garcia HE, Kim JS, Bragg-Sitton SM. Operations optimization of nuclear hybrid energy systems. NuclearTechnology. 2016;195:143-56.
[6] Fritzson P. Principles of Object-Oriented Modeling and Simulation with Modelica 3.3: A Cyber- PhysicalApproach: John Wiley & Sons; 2014.
[7]Rabiti C, Kinoshita RA, Kim JS, Deason W, Bragg-Sitton SM, Boardman RD, et al. Status on the Development of aModeling and Simulation Framework for the Economic Assessment of Nuclear Hybrid Energy Systems. IdahoFalls (ID): Idaho National Laboratory, Nuclear Science and Technology Division; 2015 Sep. ReportNo.:INL/EXT-15-36451. Contract No.:DE-AC07- 05ID14517. Sponsored by the U.S. Department of Energy.

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 10, Issue 10, October 2021 ||

DOI:10.15662/IJAREEIE.2021.1010003 |

[8] Rabiti C, Alfonsi A, Mandelli D, Cogliati J, Kinoshita R. Advanced probabilistic risk analysis using RAVEN andRELAP-7. Idaho Falls (ID): Idaho National Laboratory, Nuclear Science and Technology Division; 2014 Jun.Report No.:INL/EXT-14-32491. Contract No.:DE-AC07- 05ID14517. Sponsored by the U.S. Department ofEnergy.
[9] Udagawa J, Aguiar P, Brandon NP. Hydrogen production through steam electrolysis: Model-based steady stateperformance of a cathode-supported intermediate temperature solid oxide electrolysis cell. Journal of PowerSources. 2007;166:127-36.
[10] O'Brien J. Thermodynamic considerations for thermal water splitting processes and high temperature electrolysis.ASME 2008 International Mechanical Engineering Congress and Exposition. Boston, Massachusetts, USA:American Society of Mechanical Engineers; 2008. p. 639-51.
[11]Cai Q, Brandon NP, Adjiman CS. Modelling the dynamic response of a solid oxide steam electrolyser to transientinputs during renewable hydrogen production. Frontiers of Energy and Power Engineering in China. 2010;4:211-22
[12] Udagawa J, Aguiar P, Brandon NP. Hydrogen production through steam electrolysis: Model-based dynamicbehaviour of a cathode-supported intermediate temperature solid oxide electrolysis cell. Journal of PowerSources. 2008;180:46-55.
[13]Palsson J, Selimovic A, Sjunnesson L. Combined solid oxide fuel cell and gas turbine systems for efficient powerand heat generation. Journal of Power Sources. 2000;86:442-8.
[14] Krull P, Roll J, Varrin RD. HTSE Plant Cost Model for the INL HTSE Optimization Study. Reston (VA):Dominion Engineering, Inc.; 2013 Mar. Report No.:R-6828-00-01.



INNO SPACE
SJIF Scientific Journal Impact Factor
Impact Factor: 7.282

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

International Journal of Advanced Research

in Electrical, Electronics and Instrumentation Engineering

9940 572 462 6381 907 438 ijareeie@gmail.com

Scan to save the contact details