IJAREEIE

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

International Journal of Advanced Research

in Electrical, Electronics and Instrumentation Engineering

Volume 9, Issue 10, October 2020

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 7.122

9940 572 462 | 6381 907 438 | ijareeie@gmail.com | www.ijareeie.com

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

|| Volume 9, Issue 10, October 2020 ||

Modelling and Simulation of Gas Turbine and Controlling the Sudden Change in Load

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ABSTRACT: Variable energy resources, like wind and solar power, require a special attention due to the challenges that its intermittent nature poses to the power grid operation. To safely integrate these energy sources to power systems, acceptable levels of reliability and security and affordable prices are required. The operational flexibility of gas power plants makes them a good complement to variable renewable sources. It is very likely that policies will promote the increase of gas power, at least in the next decade, especially because they produce less emissions than coal power plants. This paper investigates how the multi-domain physical modeling and simulation Modelica language has been employed to create a benchmark power grid and gas turbine model. The modeling approach is useful to test the functionalities of the gas turbine, and it also could give rise to potential applications in power system domain studies where the widely-accepted turbine-governor models are not rich enough to represent the multi-domain system dynamics. The first package aimed to include the elementary gas turbine topologies. The SingleShaftGT model represents a single shaft gas turbine and it is based on the Plant model of the Brayton Cycle examples of Thermo Power. The second package has the generation groups, this package provides an additional interface block was created to allow the connection between the electro-mechanical generator model and the detailed gas turbine model. The third package includes the electrical network with variable load, and the control models which are based on Modelica library components.

KEYWORDS: Modelica language, gas turbine, ThermoPower, SingleShaftGT,GGOV1.

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 modelling 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 modelling 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 Hairier et al (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 Media library 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.

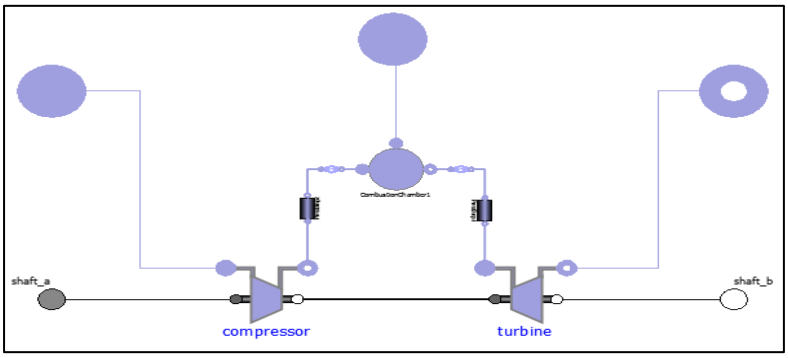

Fig. 1:The simulation platform

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. SIMULATIONRESULT AND DISCYSSION

The first step in the analysis to be conducted on the SMIB community models is the identification of the GGOV1 turbine model that is equivalent, in phrases of its open-loop time response, to the ThermoPower model. An open-loop check has been applied to the multi-domain SMIB model for that purpose. The governor has been removed from the multi-domain SMIB model to follow a step change on the fuel mass flow rate in the gas turbine model, as shown in fig 2.

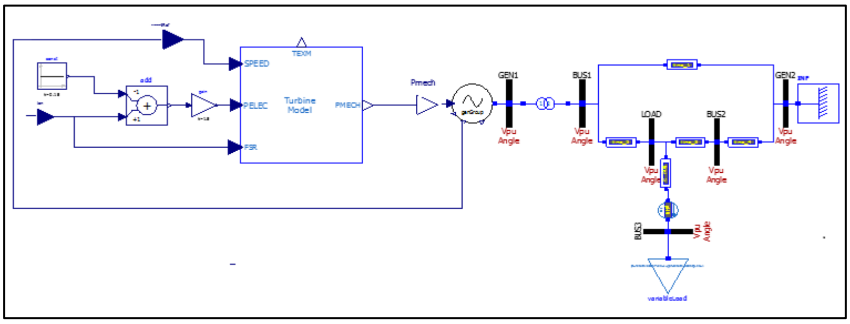

Fig.2: SMIB model without governor

Table 1, was employed to find the fuel mass flow fee values that give an output mechanical power change from 5 to 8 MW. A simulation was carried out in Modelica with a duration of 100 seconds, where the step change occurred after 30 seconds. The values of turbine gain $Kturb$ and the no load fuel flow $Wfnl$ were set to be 1.5 and 0.14, respectively. Additionally, the damping factor Dm was set to the typical value of 0.Thus, it has only been required to obtain the values of the parameters of the lead-lag transfer function Tb and Tc, together with the delay transport time $Teng$.A

GGOV1-based turbine model with one pole and one zero with no time delay was identified. The resulting transfer function is [21]:

$$g_4(s) = K_{turb}\frac{1 + T_c s}{1 + T_b s} = 1.5\frac{1 + 0.123S}{1 + 0.139S}$$

Table 1. Fuel inlet valve model design data with $K_{turb} = 1.5$ and $W_{fnl} = 0.14$

P_{mech} (MW)	P_{mech} (pu)	$\theta_{fuel\ valve}$ (pu)	$\dot{m}_{fuel}$ Kg/s
0	0	0.14	1.90
1	0.1	0.22	1.92
2	0.2	0.28	1.97
3	0.3	0.35	2.10
4	0.4	0.42	2.13
5	0.5	0.47	2.20
6	0.6	0.55	2.27
7	0.7	0.62	2.34
8	0.8	0.70	2.41
9	0.9	0.75	2.49
10	1.0	0.82	2.56

The same step change on the fuel mass flow rate was applied on both the reference multi-domain model and the power system-only model without the governor. Fig 3, shows the output mechanical power plots from the turbine components of the models.

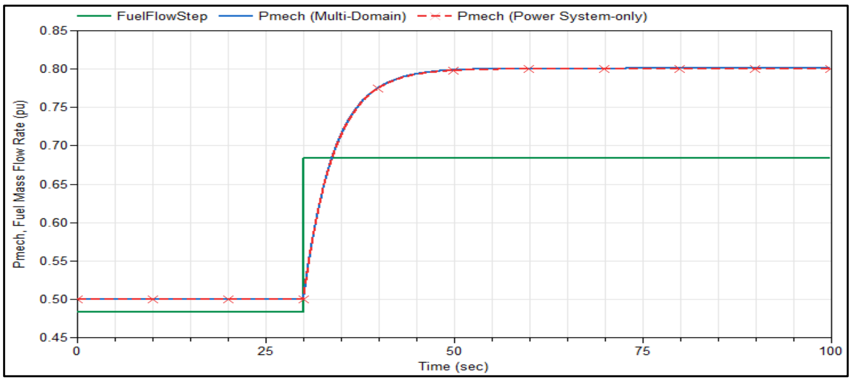

Fig .3: Open-Loop test to verify the response of the identified model

The next step is to verify the time-domain response of the models under a load change. A simulation of 100 seconds was performed on both the multi-domain and power-system model (using the identified parameters as described in the first step), with the same governor model. The governor was added to the multi-domain and power System-only models to evaluate their time response to a load change as shown in fig 4.

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|| Volume 9, Issue 10, October 2020 ||

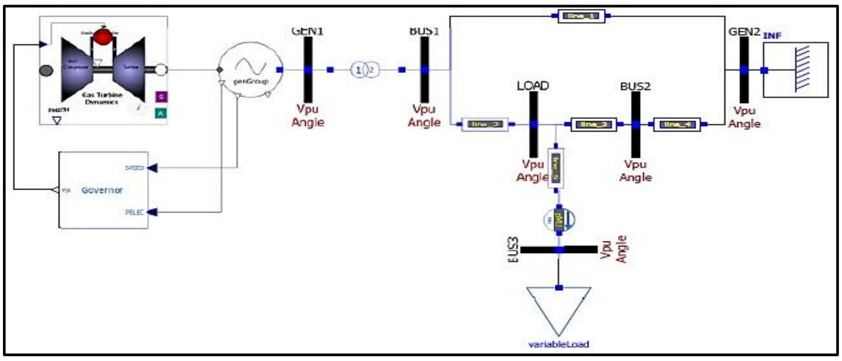

Fig. 4: Multi-domain model with the governor model from the GGOV1 model.

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

- ***The variable load*** **:**

The active power of the load was increased by 0.2 pu after 30 seconds of simulation, and was set back again to the original value after 20 seconds, as shown in fig 5, meanwhile the fig 6.4 shows the drop in the load voltage.

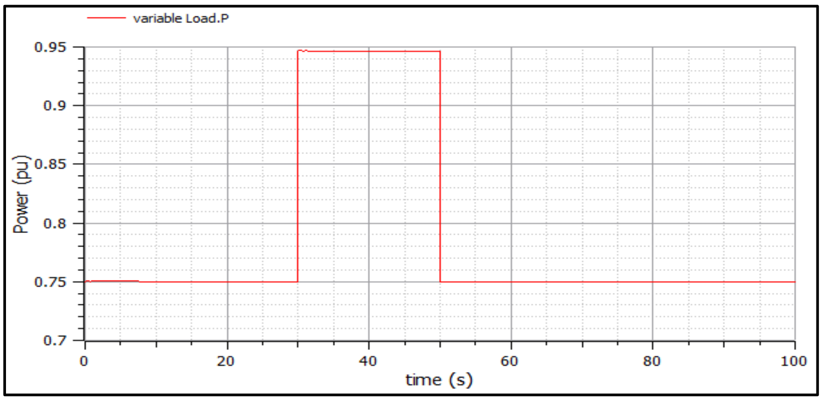

Fig. 5:The increase in active power of the load

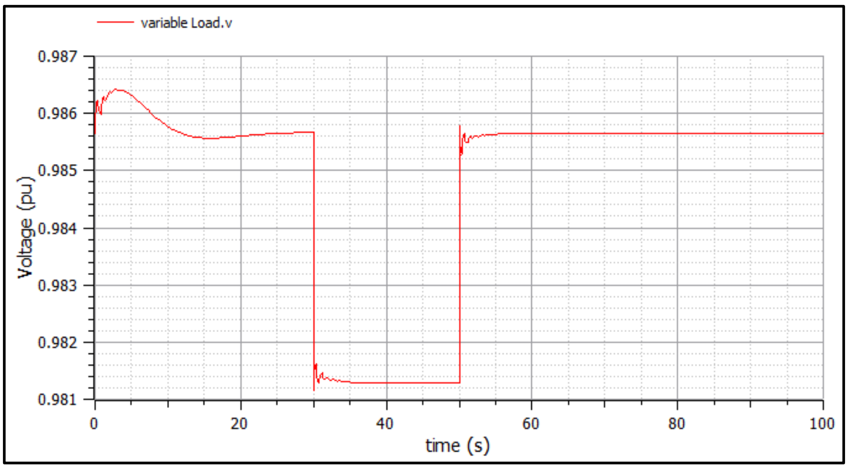

Fig. 6: The drop in the load voltage.

- ***Mechanical and Electrical power:***

Fig 7, shows a curve of the mechanical power delivered by the gas turbine components , but the turbine torque is increased with load and the rotor speed decreased as shown in fig 8.

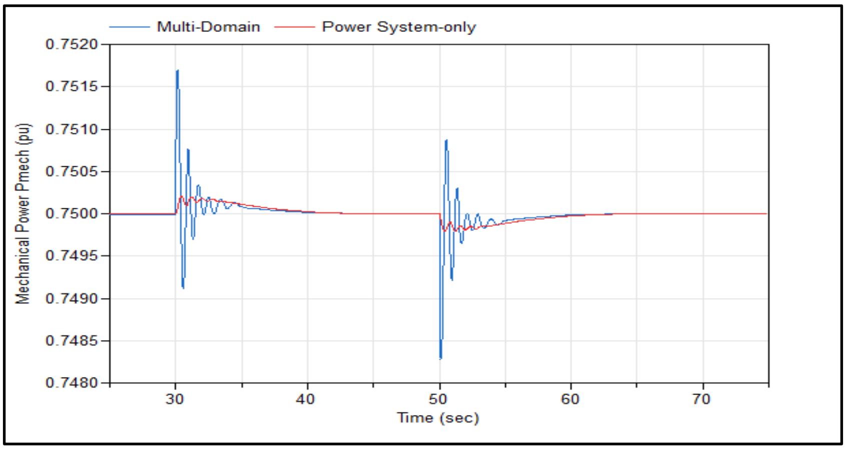

Fig.7: Mechanical power response comparison

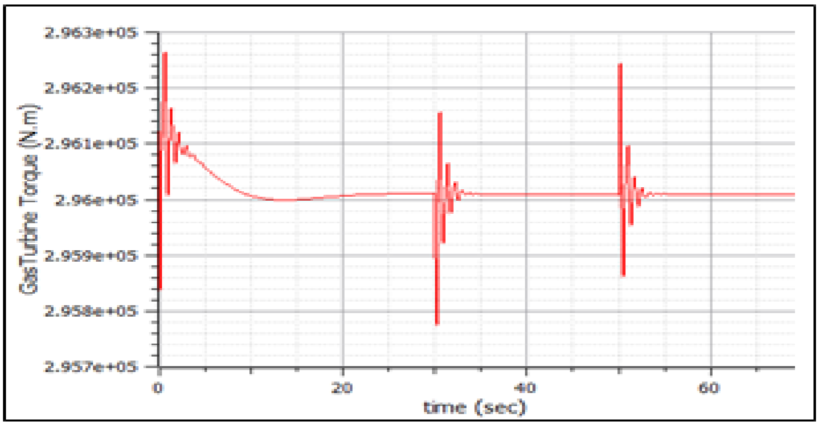

Fig.8: Gas turbine Torque

Fig 9, show the electrical power of the generator during the load change .

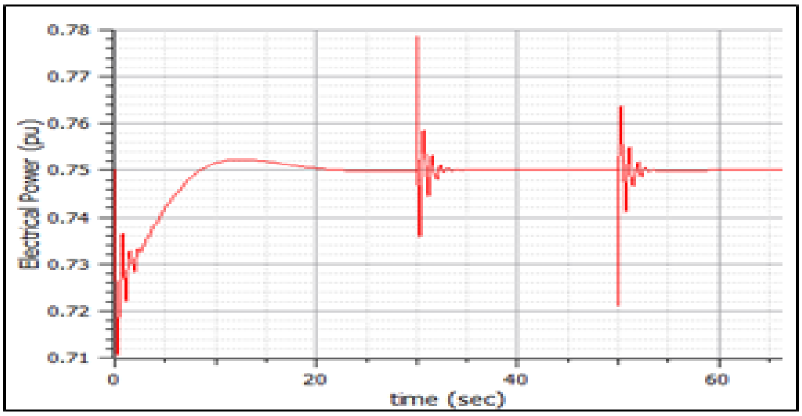

Fig. 9: The electrical power of the generator respectively.

- ***The system frequency response and speed deviation***

Special attention was given to the response of the system frequency and the turbine speed deviation from nominal. The corresponding plots are illustrated in fig 10 and 11, respectively.

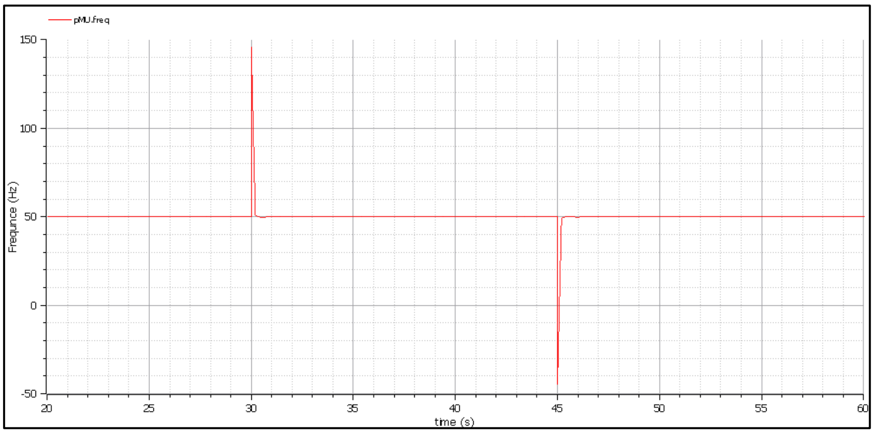

Fig.10:The system frequency response.

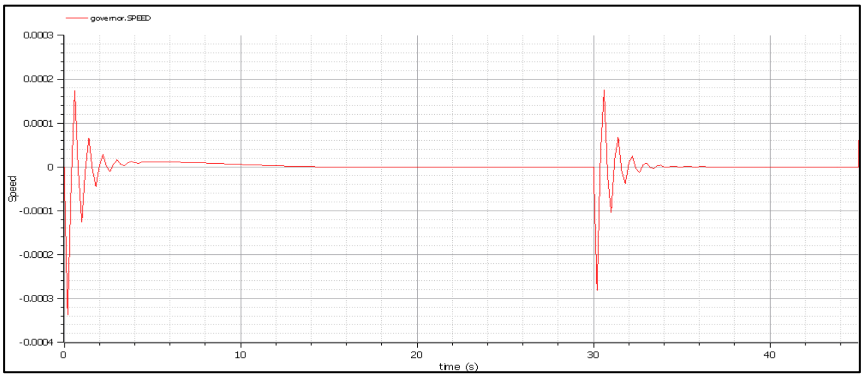

Fig .11: The turbine speed deviation from nominal

- ***Fuel demand , air flow and valve position :***

Fig 12, show the fuel demand for the gas turbine response . The fuel demand depending on the change in electrical load.However the amount of fuel required to keep the combustion process alive should be maintained,so that the valve position change to meet required amount of fuel as shown in fig 13**.**

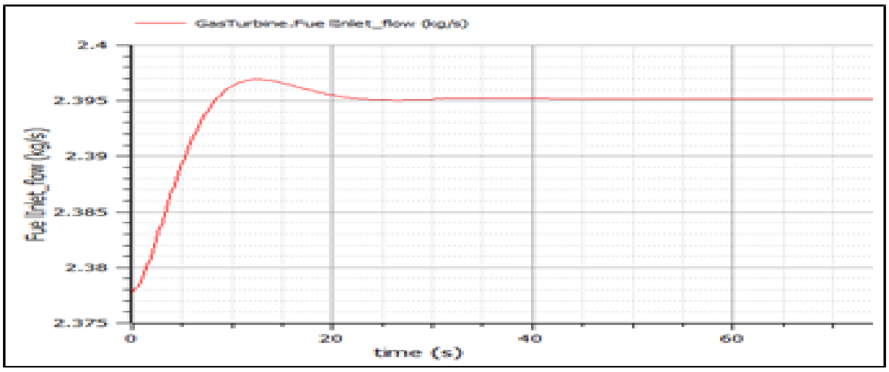

Fig .12: The fuel demand for the gas turbine response

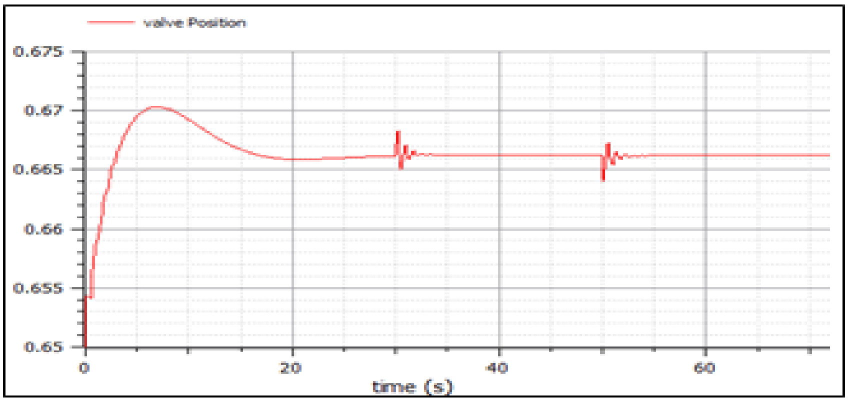

Fig .13: The valve position

Thus the amount of air inlet flow to the turbine will change, as shown in fig 14.

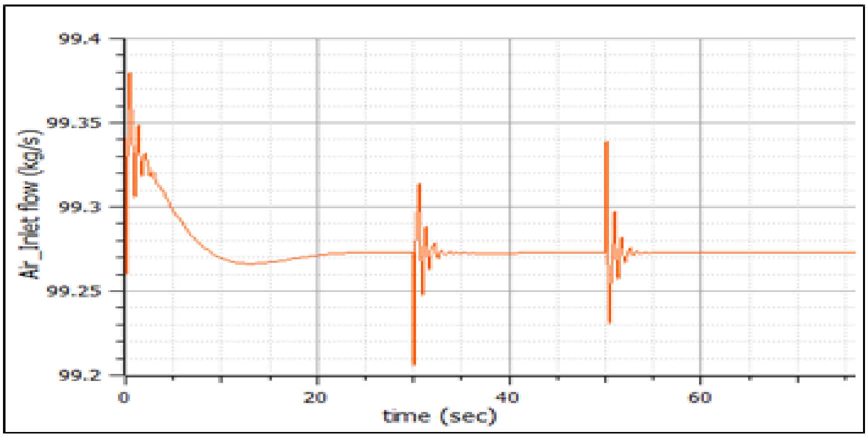

Fig .14: The Air flow to gas turbine

Increasing the fuel burned in the turbine, consequently leads to an increase in the exhaust gas temperature as shown in the fig 15..

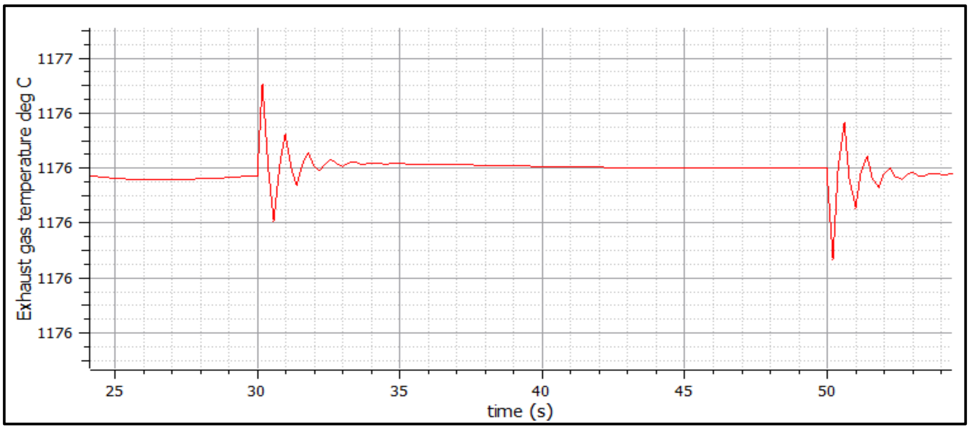

Fig .15: The exhaust gas temperature

- Discussion

The effects on the time response of the models can be examined in fig 7 to 10.The load change event influences the system frequency, which is measured closed to the load bus, and is shown in fig 10. Even if it is for a short time (around 2 sec), the frequency experiences a maximum deviation of up to 1 Hz. Such frequency excursions are unacceptable in practice as protective over/under frequency protection systems can be triggered. Observe that the power system-only model results give an over-estimation of the expected frequency, and thus, any control/protection system design using such model may give unexpected results in practice. In Fig 10, the frequency of the power system-only model goes beyond 49.6 Hz which is typically the limit for under-frequency protections, while the multi-domain model is below it making the latter more suitable for model-based design.

Figures 16and 17 together with Tables 2 and 3 lead to significant findings. In general, the explicit model from *ThermoPower* provides a higher bandwidth resolution in behaviourmodelling that is not possible with the GGOV1-based model. Therefore, this shows how a multi-domain model will be more suitable for transient stability studies (e.g. fault analysis, control design, etc.)The changes on the mechanical power in fig 7 are due to the governor's response. However, this is not in the case of the multi-domain turbine model. That explains why the model produces an additional oscillatory behaviour on the mechanical power that cannot be observed in the GGOV1-based turbine model response. Also, note that the output mechanical power is grossly under-estimated by the power system-only model with respect to the multi-domain model. The electrical power can be used to examine the impact of the gas turbine model response on the generator's electric power output, see fig 9. Nevertheless, it is important to keep in mind that the electrical power is also directly influenced by the speed. The change in the exhaust temperature, as a result of the increased amount of burning fuel, can be observed in fig15, to compensate for the decrease in turbine speed due to the sudden load, which also results a change in torque as in the fig 8.

V.CONCLUSION

In this paper, gas turbine model for power plant has been studied, and a simulation work has been conducted to investigate the behavior of the gas turbine under various disturbances. Principle building blocks of combined cycle electricity plants are the gas turbines. Due to this fact, a gas turbine model that will also include the physical nature of the machine was obtained in this study. As the modeling approach, static components that reflect the steady-state input-output relationships of fundamental physical variables were reached by curve fitting to the input-output data collected through the experiments performed. For the dynamic characteristics, they were analyzed, modified and tuned accordingly to the load control loops that are important for interconnected grid operation.Generating units in a very powerhouse, which are nominated to participate in system frequency control must not be at their maximum operating point (base load), but should be operated under "governor control" with certain, predetermined amount of reserve power. Additionally, to those facts, proper control over is correctly configured load control loops could be required. Otherwise, units will either not reply to frequency deviations or; those respond, will should load/unload in large magnitudes to an extent, frequency occurrences of which could not only drained the machine , but also lead to inadvertent grid behavior. There for, an appropriate control loop implementation is a must for all power plants.

A load change sudden test has been performed with results similar to a real gas turbine. The simulation results show that the performance of the control systems was satisfactory under each test when the gas turbine experienced high, rapid variations in the load.A Gas Turbine Power Plant was proposed as an auxiliary generator to be included in smart grid to cover rapid dynamics in grid demand that the remainder of the system cannot follow. To predict the process behavior during transients that occur in plant operation, a dynamic simulation model was developed. To evaluate the controllability of the proposed process during dynamic operation, classical feedback controllers were implemented for power frequency and temperature controls. Several case studies were performed to research the system responses to the most important disturbance (power load demand) in such an impression system.

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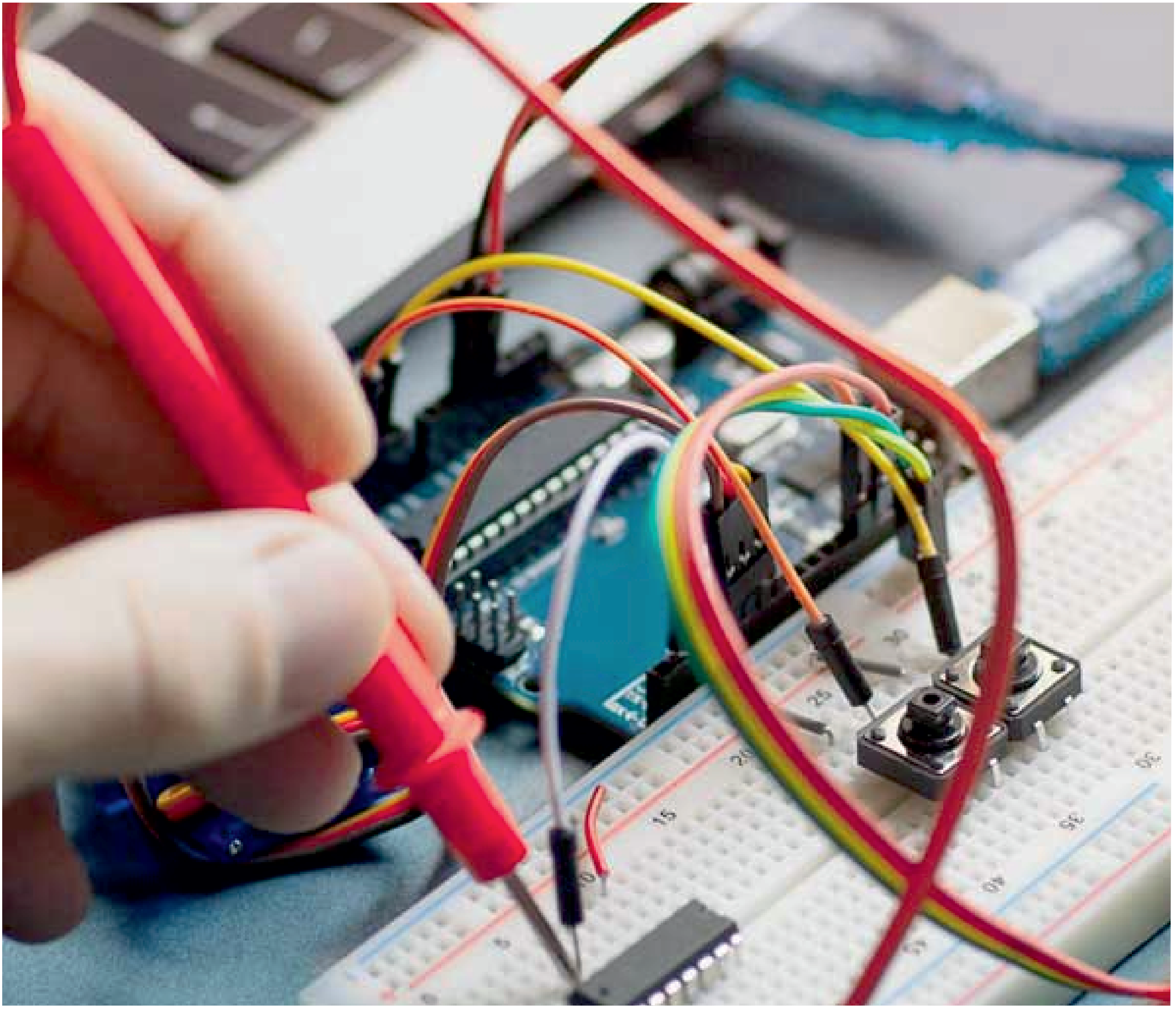

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