

Design, Simulation and Control of a Marine Ship Model's Diesel Engine using Python and Matlab/Simulink

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Marine ships engines are kind of huge diesel engines. In fact, the manner of controlling the speed of a ship can impact badly on the financial matters of the machinery operation. Thus, controlling the speed of the marine engines can avoid ships to face dangerous accidents. In purpose to prevent such kind of damages, marine systems simulator have been widely used as numerical tools. In fact, the simulation of speed control systems makes it possible to render the process of controlling the speed of an engine economical and eliminates many risks. In this article, we first present a mathematical formulation to illustrate the rotational velocity process of a ship model's marine diesel engine as well as its PID controller. Secondly, we introduce a novel python's marine simulator which includes a PID controller to govern marine ship model's engines and we compare its results with another PID diesel engine speed controller that we modelled, designed and simulated via Matlab/Simulink. Results of scenarios and experiences which we carried out have shown that the response of the speed control system when using python can be accurate and close to the one of Matlab/Simulink.

Keywords: Marine, Diesel Engine, Ship, Model, Simulation, Python, Matlab, Simulink; Towing Tank Testing, Speed-Control System

1 Introduction

For many decades, diesel engines have been extensively utilized in reality as a main power source due to its highest effective efficiency compared to all the other combustion engines. Diesel engine's industry encompasses powers generators, automobiles as well as ships [1]. In fact, marine ships engines are kind of huge diesel engines which require a tough speed control [12].

Furthermore, marine control systems or marine cybernetics is known to be the science about techniques and methods for analysis, monitoring and control of marine systems [2]. In the context of marine diesel engines, the speed control system is an important part of the engine room control and plays an important role in marine automation [3]. In reality, there is always an ultimate need of a reliable control system to regulate the speed of marine diesel engines for safe and efficient operations under different conditions and external load disturbances [4]. In fact, the manner and the degree of controlling the speed of a ship impacts badly on the financial matters and optimization of the machinery configuration and operation [5][10][11][13]. In other words, well governing, monitoring and controlling the speed of the marine diesel engines can avoid

ships to face some dangerous accidents such as collision or grounding.

In purpose to study and to prevent such kind of accidents, marine systems simulator have been widely used for years (especially those based on Matlab/Simulink) as numerical tools in system design and analysis, both in academia and in the marine industry [18][19][20]. Indeed, simulation designates the execution of a computer program on a computer or network with a view to simulate a real physical phenomenon. A Marine simulator may use models and parameters of various fidelity and under different working conditions to reconstruct the real physical properties of a dynamic system [2][6]. Thus, the simulation of speed control system is the backbone of any marine systems simulator and it obviously makes it possible to render the process of monitoring and controlling the speed of a marine diesel engines more economical and eliminates human and material risks.

In the context of both the marine engineering or also in the naval architecture, no real full scale ship can be constructed and developed without passing through ship models that will be generally well experimented and tested in towing tanks already constructed for this purpose. Which is also the same adopted approach in the field of ship model testing

when dealing with marine simulators and more specifically with speed control systems. In fact, ship model testing could be broadly divided into two main families, on one hand there are resistance tests --either in waves or still water-- and on the other, maneuvering and sea keeping tests [7]. The former ones are accomplished in towing tanks, which are lanky water channels where the model is connected to a carriage that tows it along the center of the tank. Oppositely, the latter tests are frequently carried out in the ocean basins[7]. However, commercial ship model testing is expensive, time-consuming and it suffers from scale effects. Defenders of computational fluid dynamics declare that an approach based on numerical simulation provides a flexible milieu to construct, test, and analyse ship system efficiency and performance [8][9]. This allows the simulation environment user to optimize, tune, or test possible changes in the ship design parameters, surrounding environment conditions, investigate different power sources or energy management strategies without conducting experiments each time [8][9].

Thus, the main objective of the presented work is to study, design, simulate and control a speed control system of a marine ship model's diesel engine under two different platforms, the first is the most widely used one which is Matlab/Simulink, and the second one is a novel python's developed simulator. In fact, the simulation of the diesel engine performance will be accomplished through three scenarios. In the first one, the load torque will be fixed to 85Nm whereas the mass flow of the fuel will be smoothly increased. In the second one, the load torque will be augmented from 70 Nm to 100 Nm while the fuel mass flow is constant during the whole period of the simulation and is equal to 10. To design a PID controller to control the engine rotational velocity by using the mass flow of the fuel as the input variable to the system and to simulate the performance of this PID controller for a constant load torque of 85 Nm and make the engine rotational velocity reach 2000 rpm will be the subject of the third simulation.

2 The Mathematical Model of our Marine Ship Model's Diesel Engine Speed-Controller System

In this work, a four cylinder diesel marine will be simulated via this first ordinary differential equation:

$$\frac{dN}{dt} = \frac{60}{2\pi} \frac{\tau_e - \tau_l}{I_e} \quad (1)$$

Notice that N is the engine rotational velocity [rpm], τ_e and τ_l are engine and load torques respectively. I_e is the engine moment of inertia. The engine torque is calculated as this:

$$\tau_e = \frac{P_{me} V_d}{v 2\pi} \quad (2)$$

Where

$$P_{me} = e P_{mf} - P_{mr} \quad (3)$$

And

$$P_{mf} = \frac{H_u m_f}{V_d}; \quad H_u = 45 \text{ MJ/Kg}; \quad m_f = \frac{1}{\text{cyl}} \frac{W_f}{60} \quad (4)$$

Since it is four cylinder diesel engine then $\text{cyl} = 4$, V_d is the displacement volume of the engine, P_{me} is the mean effective pressure, P_{mf} is the mean fuel pressure, P_{mr} is the mean friction pressure, m_f is the mass of the fuel in a cylinder during a cycle and H_u is the fuel calorific value. v is taken 1 for two stroke engines and 2 for four strike engines. W_f is the mass flow of the fuel. The initial condition of the engine rotational velocity is 1500 rpm.

e is a coefficient used for the calculation of the mean effective pressure P_{me} using the mean fuel pressure P_{mf} and the mean friction pressure P_{mr} . The value of the coefficient e is calculated with the formula shown in the following table, using the values of the displacement volume V_d , the engine moment of inertia I_e , and the mean friction pressure P_{mr} . Fig. 1 shows the main Graphical User Interface (GUI) of our novel marine ship model's diesel engine simulator which will help the user to set up freely these simulation's parameters. The values of V_d , I_e , e and p_{mr} are given in the table below:

Tab. 1 The values of parameters

$V_d [\text{m}^3]$	$I_e [\text{kgm}^2]$	The Coefficient e	$p_{mr} [\text{Kpa}]$
0.0023	0.2750	$110V_d [\text{m}^3] + 0.01I_e [\text{kgm}^2] - \frac{p_{mr} [\text{Kpa}]}{1750}$	145

The interested reads are referred to [14][15][16][17] for more examples of mathematical

models and formulations of marine diesel engines and their corresponding speed control systems.

Fig. 1 The main GUI of our novel marine ship model's diesel engine simulator developed using python

3 Marine Diesel Engines Simulation and Control

- Simulation 1: In this first scenario we use a constant load torque which is equal to 85 Nm and a smoothly increasing mass flow of the fuel ;

As it was explained above in the introduction part,

in this scenario the load torque will be fixed to 85Nm during the whole period of simulation which is equal to 10 seconds (Fig. 3-D), whereas the mass flow of the fuel will be smoothly increased according to a slope that can be chosen by the user otherwise its default value is 1 while using our python program, however when using Matlab/Simulink a ramp block has been used for a smoothly generation of the mass flow of the fuel which rises from 0 to 10 in 10 seconds (Fig.3-C).

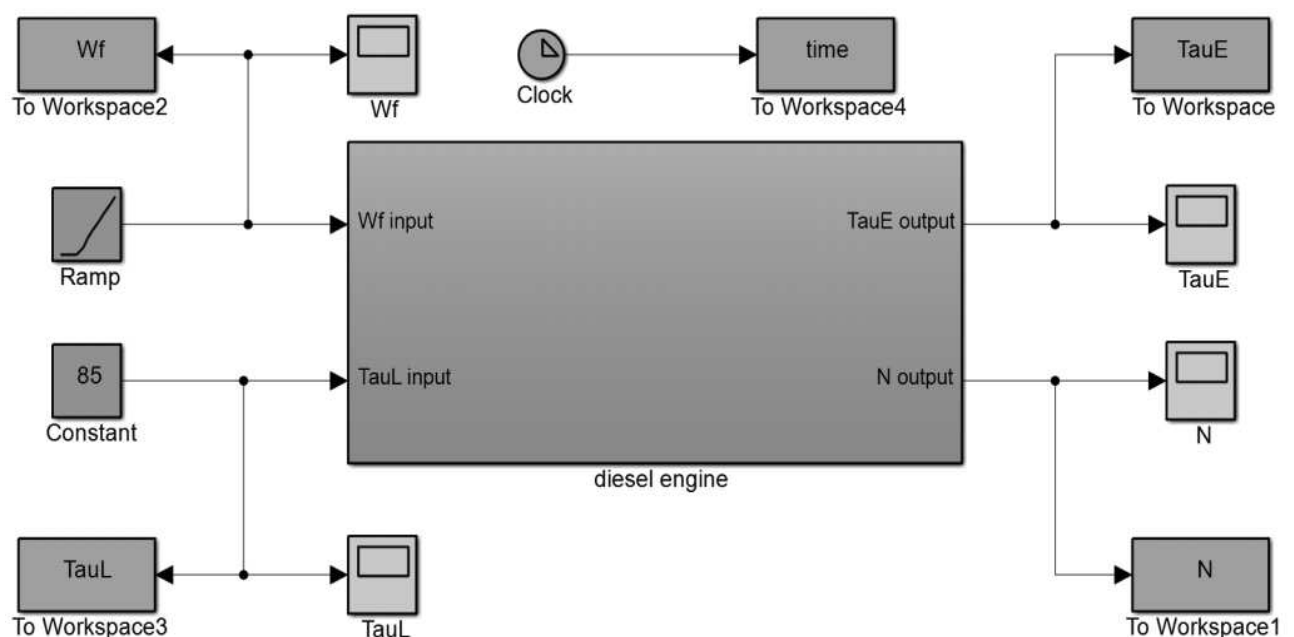


Fig. 2 The equivalent Matlab/ Simulink model of the first simulation

In terms of engine's speed, Fig.3-A shows that in the beginning of the period of the simulation, when using Matlab/Simulink, the speed of the engine drops from the initial speed which is 1500 rpm to around 300 rpm. After about 5 seconds of the beginning of the simulation, the speed increase again to 1500 rpm because of the increase of the mass flow of the fuel. The speed of the engine keeps rising after that and reaches the value of 2622 rpm at the end of the simulation. However, when using our novel python's simulator the speed of the engine drops a little bit from the initial speed which is 1500 rpm to around 1450 rpm and 3 seconds later the speed increases steadily

again to reach the value of 1800 rpm at the end of the simulation. In relation with the engine torque (Fig3. B), for both curves the Matlab/Simulink one as well as the one generated via the python simulator increase with the rise of the fuel mass flow. In fact, for the first 5 seconds the Matlab's curve representing the engine torque increases rapidly and with higher value comparing to the one of python. However, starting from the second number 6 both curves show almost the same behaviour by reaching the value of 95 Nm and staying almost stable at this value till the end of the simulation.

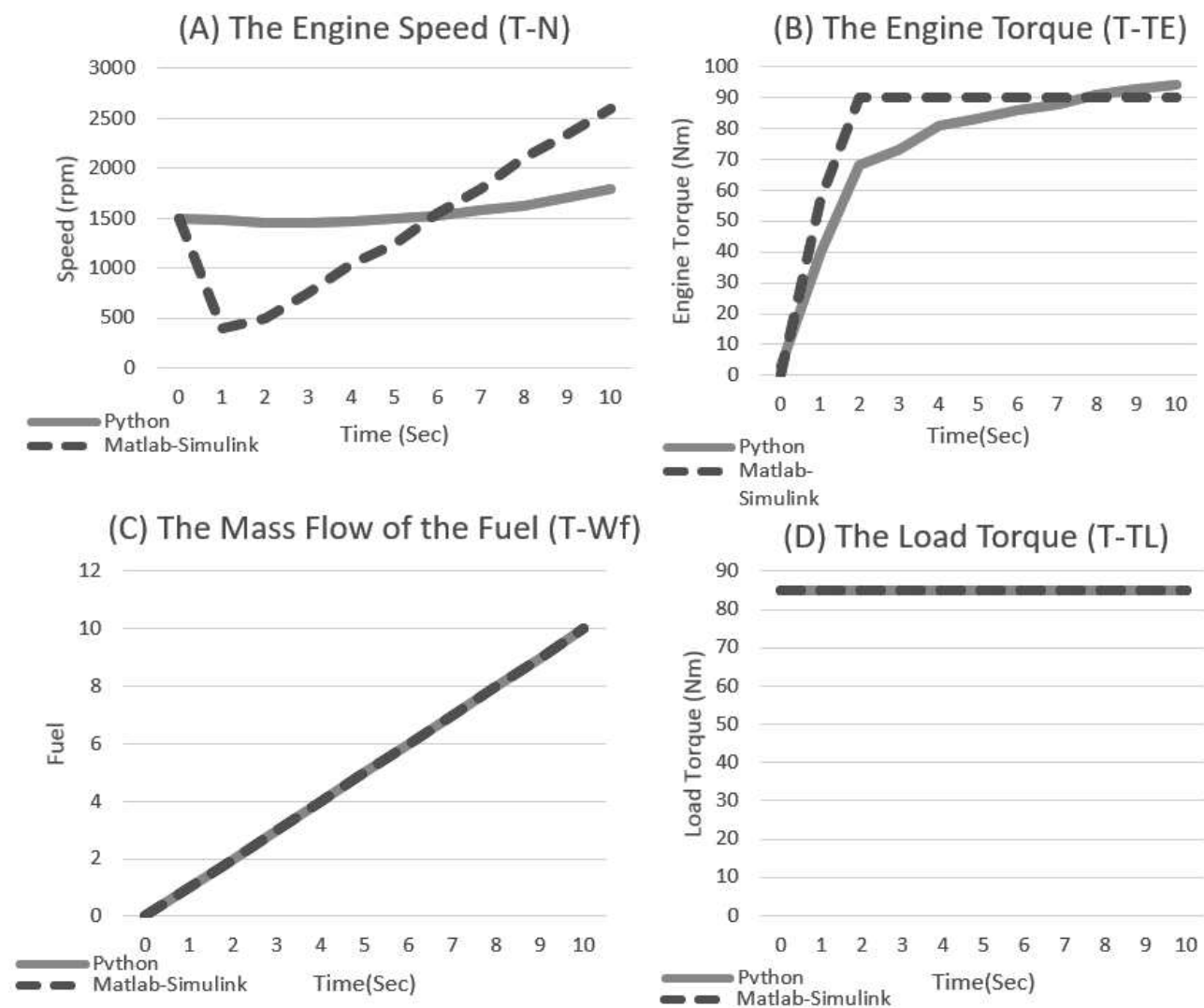


Fig. 3 Simulation results under the first scenario using python and Matlab/ Simulink

- Simulation 2: In this second scenario we use a smoothly increasing load torque and a constant mass flow of the fuel which is equal to 10;

In this second scenario, the fuel mass flow w_f is equal to 10 (Fig.5-C) and will be constant during the whole period of the simulation, whereas the load

torque will be generated increasingly from 70Nm to 100Nm in 10s with a slope equal to 3 (Fig.5-D). In the case of Matlab/Simulink the load torque is generated with the use of the ramp block while when using Python it is ensured via an increased function that rises the target output value according to the personal slope that can be entered freely by the user through the GUI.

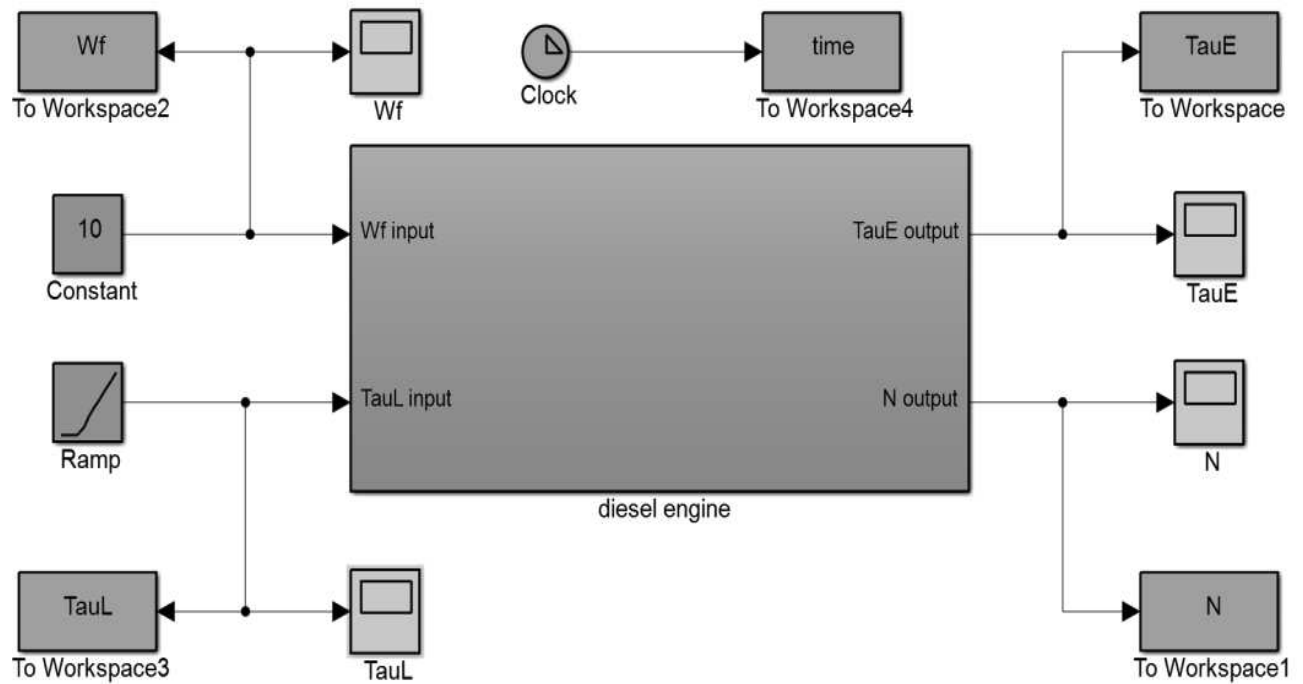


Fig. 4 The Equivalent Matlab/Simulink model of the second simulation

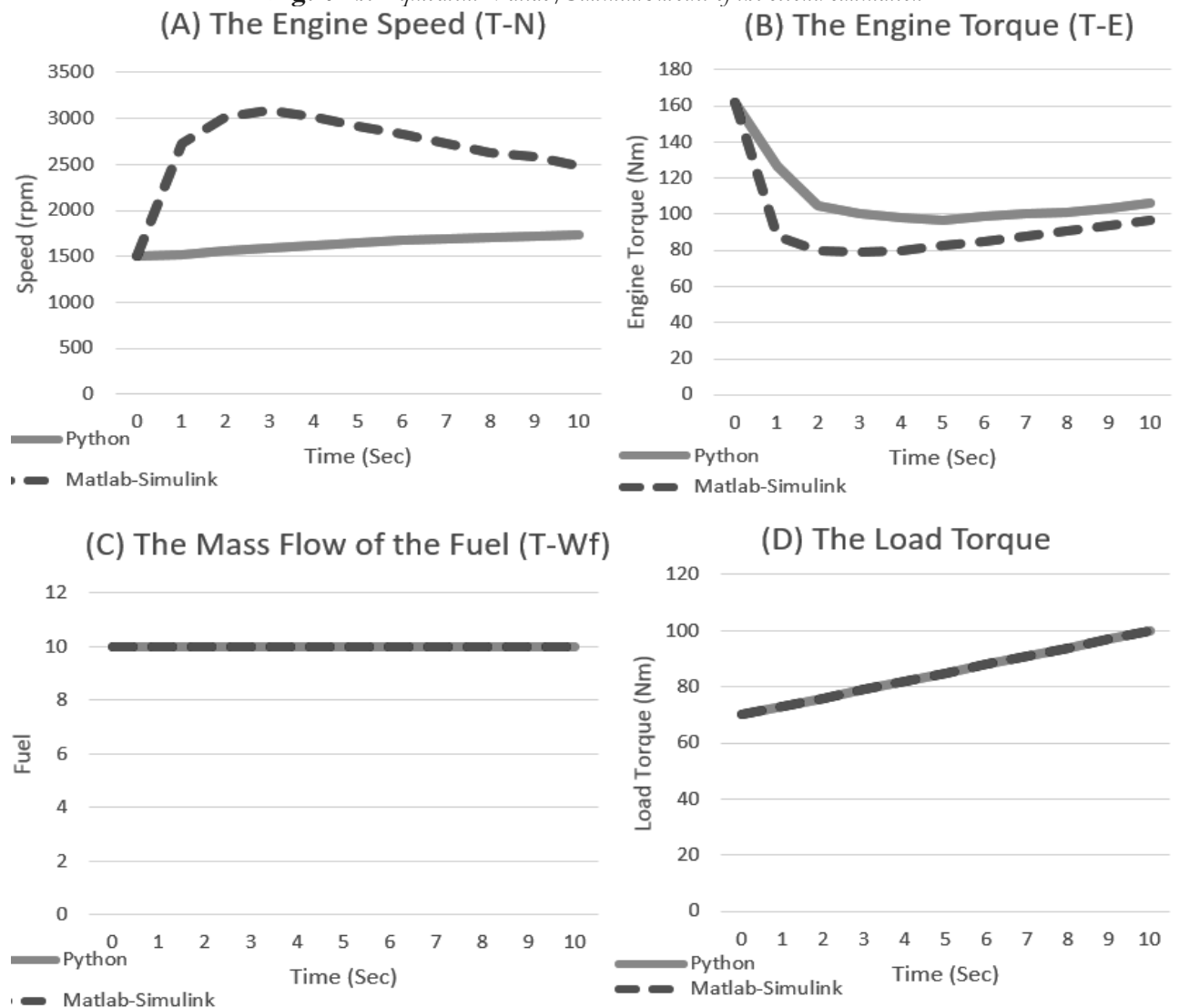


Fig. 5 Simulation results under the second scenario using Python and Matlab/Simulink

Concerning the engine's speed (see Fig. 5-A), in the first 3 seconds, when using Matlab/Simulink, the speed of the engine increases from 1500 rpm to a maximal value of about 3092 rpm. After that the speed of the engine starts decreasing and reaches the value of 2484 rpm at the end of the simulation. Meanwhile, the python engine's speed curve rises steadily from 1500 rpm to reach the value of 1800 rpm at the end of the simulation. In connection with the engine torque (Fig 5. B) in the first 3 seconds, both line graphs show almost the same behaviour, in fact whether it is for Matlab/Simulink curve or python's one the engine torque is decreasing from the value of 162 Nm to the value of 78 Nm and from 162Nm to 90Nm respectively due to the fact that the speed of the engine is rising rapidly during this period. After that, the engine torque starts rising for both line graphs because the speed of the engine is decreasing. When using Matlab/Simulink the torque reaches the value of 97

Nm at the end of the simulation whereas it reaches the value of 105Nm in while using Python's simulator.

- Simulation 3: In this third simulation we use a constant load torque which is equal to 85 Nm and a mass flow of the fuel controlled by a PID controller;

The main idea behind this third scenario, is to use a PID controller as a marine diesel engine speed governor to reach the speed of 2000 rpm at the end of the simulation. In fact, as it was explained in [3] the marine diesel engine speed control system is an important part of engine room control and plays an important role in marine automation. In this work, we adopted the traditional PID control method since it is the most extensively deployed in the marine diesel engine speed governor and which has the advantages of simple structure, good adaptability and strong stability [3].

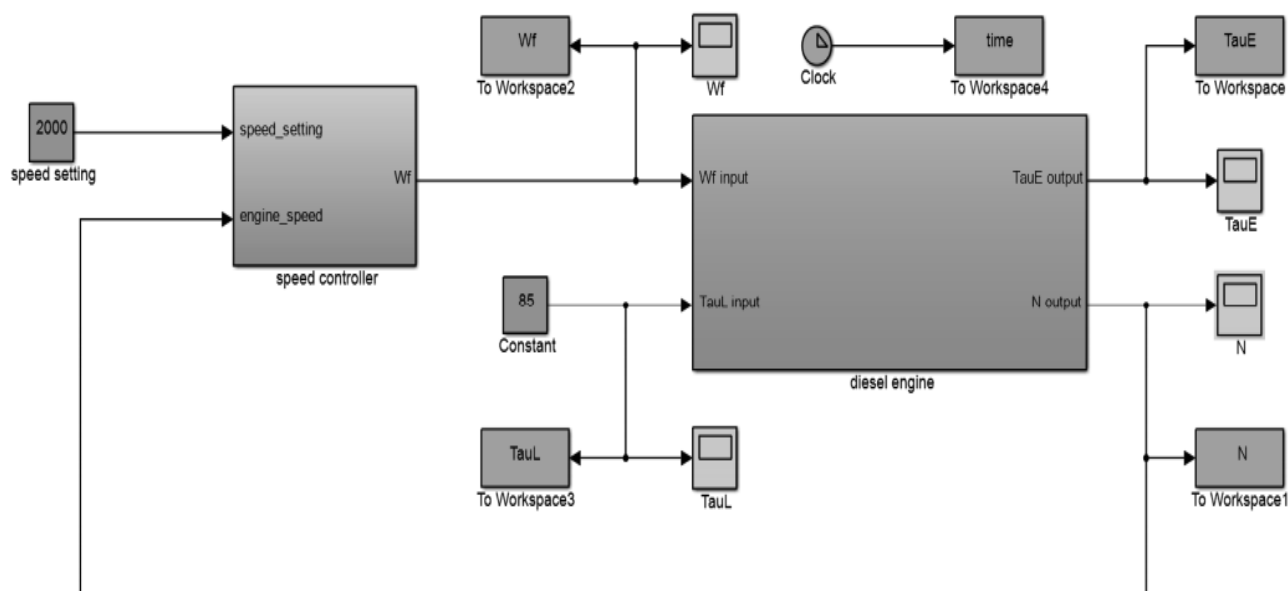


Fig. 6 The Equivalent Matlab/ Simulink Model of the third Simulation

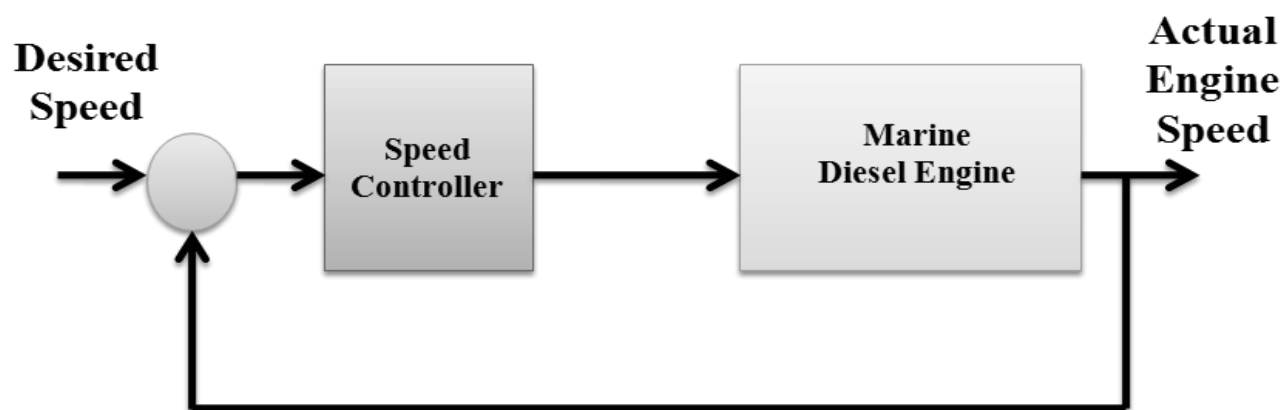


Fig. 7 Speed control system of a marine diesel engine

Our general marine diesel engine speed control systems is presented in Fig. 7 and it is equivalent using

Matlab/Simulink is shown in Fig.8.

For the purpose of simulating and comparing our

marine diesel engine speed control system using Python and Matlab/Simulink, we developed and implemented a PID controller's algorithm via this simplified

mathematical formulation :

$$w_{f_{final}} = w_{f_{initial}} + K_p \Delta N + K_i \int_0^t \Delta N dt + K_d \frac{d\Delta N}{dt} \quad (5)$$

Where : $\Delta N = [(Desired_Engine_Speed) - (Actual_Engine_Speed)]$

and where K_p , K_i and K_d all non negative, indicate the coefficients for the proportional, integral and derivative terms respectively. $w_{f_{final}}$ is the produced fuel mass flow that will be injected to the marine diesel engine, whereas $w_{f_{initial}}$ is its initial value that will be

injected to the controller. While using Matlab/Simulink, the optimal parameters of our PID controller are: $K_p = 2785 * 10^{-5}$, $K_i = 2000 * 10^{-5}$, $K_d = -114 * 10^{-5}$. However, when using our python simulator we set the PID controller with these parameters: $K_p = 5708$, $K_i = 290$, $K_d = -2970$.

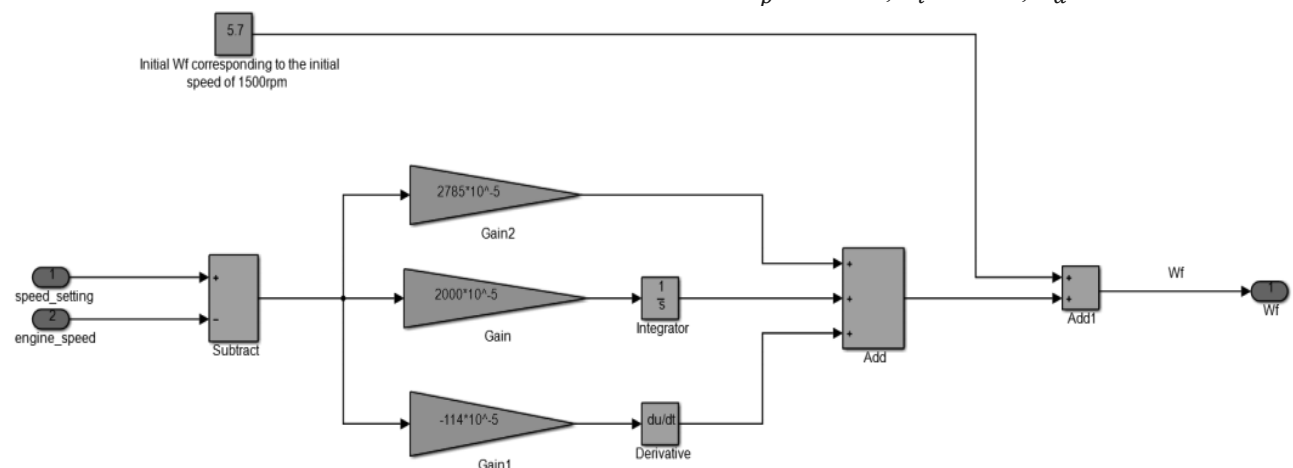


Fig. 8 The Internal design of our speed control system of marine diesel engine using Matlab/ Simulink

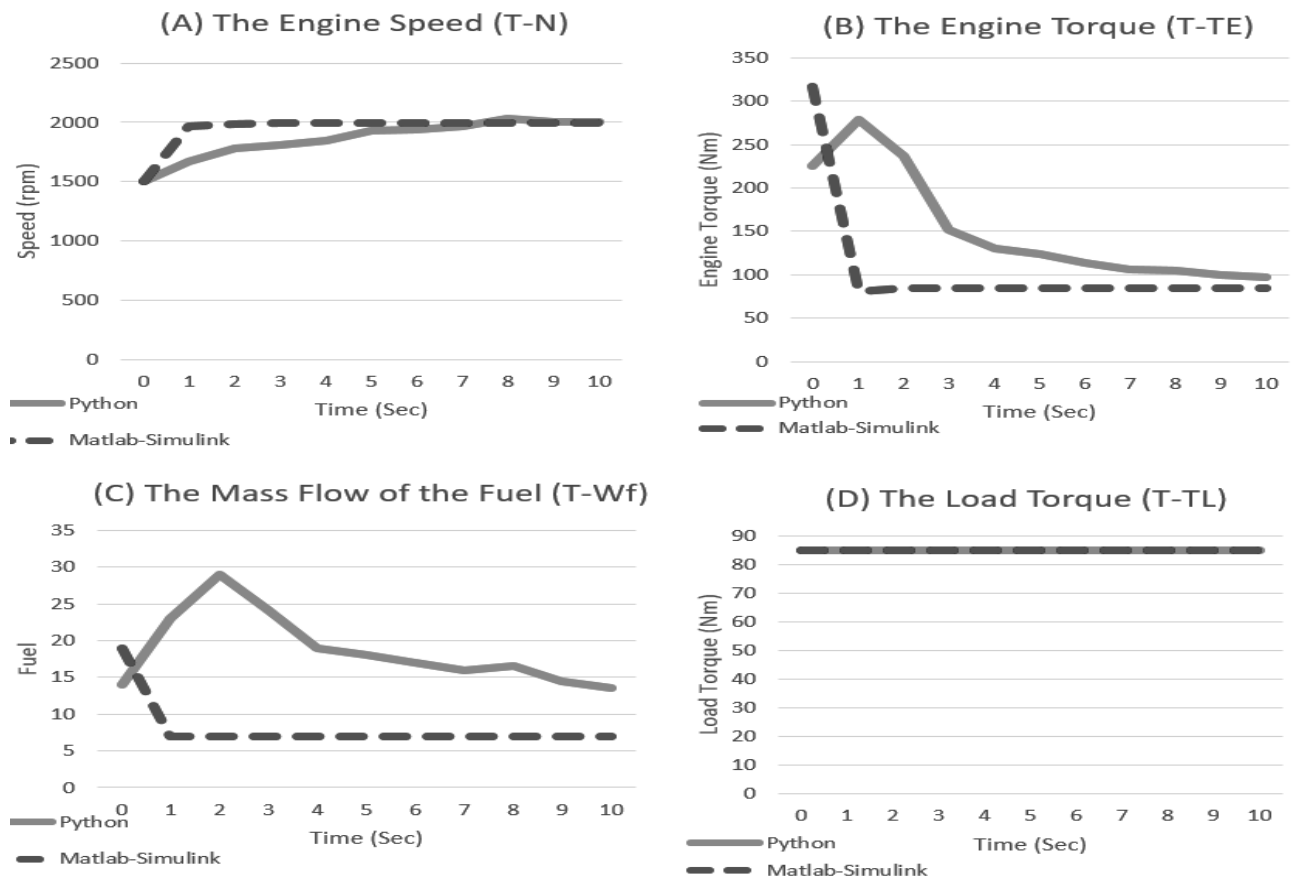


Fig. 9 Simulation results under the second scenario using Python and Matlab/ Simulink

In this third scenario, whether using Matlab/Simulink or our novel python's simulator the load torque is constant and it is equal to 85 Nm during the whole period of the simulation (see Fig.9-D). Furthermore, Fig.9-C shows the shape of the fuel mass flow w_f generated by the PID speed controller after its tuning. In fact, while using Matlab/Simulink, the initial value of w_f is 19 which drops to the value of 7 after the first second and remains constant until the end of the simulation. However, while using python the fuel mass flow w_f rises to about 30 during the first two seconds of the time of the simulation then it declines gradually as times of the simulation goes by to arrive to the value of 13 and stays almost stable at the end of the simulation (see Fig.9-C). In terms of engine's speed, Fig.9-A shows that either using Matlab/Simulink or our python's simulator the controller has proven that it is well tuned since both curves representing the engine's speed reach the value of 2000 rpm after few seconds and stay stable at it. Finally, Concerning the engine's torque, for both curves the Matlab/Simulink (see Fig.9-B) one as well as the one generated via the python simulator drop after few seconds of starting the simulation because the engine speed is rising, then it becomes constant at the end of the simulation since both the engine speed N and the fuel mass flow w_f are constants as well.

4 Conclusion and Perspectives

In this article, we mathematically modelled a four stroke four cylinder marine ship model's diesel engine with a PID controller and simulated them via two different methods. In the first one, we developed a novel marine ship model's diesel engine simulator using python language capable of letting the user to enter the different parameters of the simulation and visualizing as well as plotting the corresponding results. However in the second method we developed the same diesel engine model and its PID controller but this time with the help of Matlab/Simulink environment. In order to validate the efficiency and the accuracy of our developed marine ship model's diesel engine and its PID controller we compared the simulation results of both the novel python's simulator and those found through Matlab/Simulink environment.

This conducted comparison wouldn't have a meaning without experimenting the proposed diesel engine's model and its PID controller under different scenarios and tests. In fact, the accuracy of the final results have shown that our novel python's simulator can also be a promising interactive tool for controlling and simulating marine ship model's diesel engine the same as the famous Matlab/Simulink platform. As further perspectives of this work, we are planning to optimize the PID controller's parameters using a Ge-

netic Algorithm (GA) and an Evolutionary Programming (EP) algorithm, which will considerably improve the diesel engine control effect and performance. Additionally, the real-time control of the marine diesel engine speed and predicting the ship power and resistance can be also modelled, investigated and injected into our novel python's simulator.

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