PEOPLE’S DEMOCRATIC REPUBLIC OF ALGERIA
MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH
UNIVERSITY OF MOHAMED BOUDIAF – M’SILA

Faculty of technology

Department of electrical engineering

N° : ……………………………………

1985
جامعة محمد بوضياف - المسيلة
Université Mohamed Boudiaf - M'sila

Field: Electrotechnical

Branch: Electric control

Thesis presented to obtain the academic Master's degree

By: OUSSAMA SEDDOUK

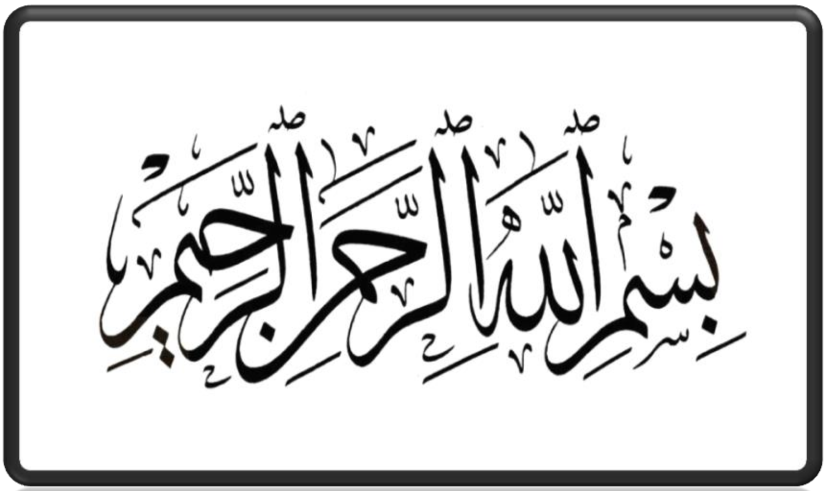
MODELING AND CONTROL DIESEL ENGINE DRIVEN A GENERATOR WITH PID REGULATOR

Title:

Defended in front of the jury composed of:

Dr. ……………….	University of Mohammed Boudiaf M’sila	President
Dr. DJERIOU Salim	University of Mohammed Boudiaf M’sila	Supervisor
Dr. ………………….	University of Mohammed Boudiaf M’sila	Examiner

Academic year: 2022 /2023



Didecation

Thanks to Allah the almighty the one who gives courage and everything to reach my goals and ending up my work.

I am highly indebted to my supervisor Dr. Salim DJERIOU for sharing expertise and valuable guidelines which were of extreme help to me.

take this opportunity to express my deep and special thanks to my mother, and my dad to my brothers , to all my close friends who supported me throughout this work may Allah preserve all of them.

Thank you to everyone who contributed directly or indirectly.

To all the family SEDDOUK.

Abstract

The interruption of electrical power in the industry generates disturbances in networks and disturbances for the user, the no connects the remote area to electrical network, a diesel generators set is an independent member capable of producing electrical energy and ensuring the continuity of energy regarding efficiency and performance. our project controls a solution for individual diesel driven generator based on classical proportional-integral-derivative regulation principles to control two essential parameters which are a frequency and a voltage at a terminal of generator, a modelling and simulation are presented to improve these parameters using MATLAB Simulink.

Résumé :

L’interruption d’alimentation électrique dans l'industrie provoque des perturbations sur le réseau électrique et des perturbations pour les utilisateurs ainsi les zones n'ont pas connectée au réseau électrique à cause de leur distance, le groupe électrogène diesel est un élément indépendant capable de produire de l'énergie électrique et d'assurer la continuité de l'énergie en ce qui concerne à l'efficacité et à la performance. Notre projet contrôle une solution pour un générateur diesel unique basée sur les principes de régulation conventionnels des dérivées proportionnelles et intégrales pour contrôler deux paramètres clés, la fréquence et la tension à l'extrémité du générateur a été présenter. La modélisation et la simulation sont effectuer pour optimiser ces paramètres à l'aide du MATLAB Simulink software.

Summary

CHAPTER I

Diesel engine: generalities and modeling

LIST OF FIGURES

Rating table

Chapter one:

TDC: Top Dead Center.

BDC: Bottom Dead Center.

V_c: Cylinder capacity (m^3).

V_d: The total displacement (m^3).

n_{cyl}: The number of cylinders.

r_c: The compression ratio.

V_m: The dead volume (m^3).

L: Length of the cylinder (m).

η_{global}: The global efficiency (%).

η_{comb}: The combustion efficiency (%).

η_{cycle}: The cycle efficiency (%).

η_{th}: The thermodynamic efficiency (%).

η_{mec}: The mechanic efficiency (%).

η_v: Volumetric efficiency (%).

ρ_{air}: The air density ($Kg.m^{-3}$).

m_{cyl}: The mass of air lost from a cylinder during each cycle (Kg).

$\dot{m}_{cyl}$: the amount of air lost from a cylinder during each cycle ($Kg.s^{-1}$).

N: The camshaft's rotational speed (tr/min).

SFC: Specific fuel consumption.

η_{ess}: The essentiality conversion rate.

m_f: La masse diesel induite dans les cylindres en un cycle moteur ($Kg.s^{-1}$).

Q_{diesel}: La constante énergétique de diesel (J/Kg.K).

P: Motor's output power.

n_R: The number of spins per cycle.

N_e: crankshaft rotational speed (tr/min)

m_{air}: The mass of air ($Kg.m^{-3}$).

m_{fuel}: The unit mass of fuel ($Kg.m^{-3}$).

λ: The mass ratio.

λ_s: The stoichiometric ratio.

W_i: The indicated work of the motor.

P_{cyl}: The cylinder's pressure.

V_e: The cylinder's volume.

IMP: Indicated Mean Pressure.

V_{cyl}: The displaced volume of the cylinder (m^3).

C_i: The indicated torque (N.m).

C_e: The effective torque (N.m).

C_{frot}: The friction couple(N.m).

EMP: Effective Mean Pressure.

FMP: Friction Mean Pressure.

t_{ing}: The injector's time of opening (s).

P_{inj}: The injector pressure (Pa).

m_{inj}: The amount of fuel injected ($Kg.s^{-1}$).

CO: Carbon monoxide.

HC: Unburnt hydrocarbons.

NO_x: Nitrogen oxides.

ϕ_{pap}: Throttle opening angle (^{o}).

$P_{am\text{-}pap}$: Pressure upstream of the butterfly valve (Pa).

$T_{am\text{-}pap}$: Temperature upstream of the butterfly valve (^{o}K).

P_{col}: Pressure in the intake manifold in (Pa).

m^*_{pap}: Air mass flow through the butterfly valve ($Kg.s^{-1}$)

C_d : The head loss coefficient.

γ: Specific heat ratio for air.

$f(\phi)$: The opening section of the butterfly valve.

$g(P_r)$: The function no continuous linear.

T_{cal} : The temperature inside the intake manifold (^{o}K).

τ_λ, is the time constant of the probe.

MBT: Maximum Best Torque.

$m^\cdot_{fv}(t)$: The mass flow of diesel admitted into the cylinders ($Kg.s^{-1}$).

$m^\cdot_{ff}(t)$: The flow mass of diesel in liquid form ($Kg.s^{-1}$).

δ_{av}: Angel of injection (^{o})

μ: The crank connecting rod manufacturing factor.

Fg: The gas force.

Fj: The inertia force.

S: The surface of the piston head (m^2).

c: The stroke of the piston.

m_b: The mass of the connecting rod (Kg).

m_{gp}: mass of piston group (Kg).

m_j: mass of the connecting rod participated in the movement of the piston (Kg).

C_m: the motor torque(N.m).

θ: angle du camshaft (rad)

$\dot{\theta}$:régime instantané du moteur thermique (rad. s^{-1}).

$\ddot{\theta}$: the angular acceleration of the crankshaft (rad. s^{-2}).

J: the moment of inertia of the motor shaft (Kg.m^2).

J_{eq}: the equivalent moment of inertia of the rotating masses (Kg.m^2).

M_{eq}: the equivalent mass of alternating masses.

Chapter two:

R_a: Resistance of a phase of the stator (Ω).

i_a, i_b, i_c : the currents through windings a, b, and c respectively (A).

V_a, V_b, V_c: the voltages across windings a, b and c respectively (V).

V_d, i_d: Component in the direct rotor axis of the voltage and current per phase after Park transform.

V_q, i_q: Component in quadrature axis of the rotor of voltage and current per phase after Park transformation.

Φ_d: Component of the flux rotating along the direct axis of the rotor (Wb).

Φ_q: Component of the flux rotating along the axis in quadrature of the rotor (Wb).

θ: Electric angle of the direct axis of the rotor with the axis of the phase a (rad).

Ω_r: rotational speed of the alternator rotor (rad.s^{-1}).

V_f: Voltage across field winding (V).

Φ_f: Total flux embraced by the field winding (Wb).

R_f: Field winding resistance (Ω).

i_f: Current through field winding (A)

J: Is the moment of inertia of the rotating part (N.m).

θ: Is the electrical angle of the rotor, with respect to a fixed axis a (rad).

P_{ei}: The electromagnetic power (watt).

p: Number of pole pairs.

N_f : the dimension of a leakage inductor.

T'_d : the dimension of a time constant (s).

T'_{d0}: the dimension of a time constant (s).

General Introduction

In today's society, all activities, whether professional or private appear to interrupt or disturbance of distribution of electrical energy, that disturbances can become unbearable user [1].

In areas not connected to the electrical energy distribution network, remote zones, a generator is essential in the following areas to equipped it, where it is technically impossible to build an electrical network or economically unsustainable, and electricity is a factor necessary development.

Public networks are not always able to handle the intensity the electricity that many businesses need to run on this provide energy for the sustainability of their activities. Overcome all shortcomings and punctual breakdowns of public networks, generators constitute mobile power, has been developed and perfected [3].

This project begins with a brief generality on the basics of operation the diesel engine as well as the mechanical principal of gasoline injection and the reaction process, the control of speed engine and a dynamic model of the various engine components has presented, also the results of the engine are discussed in the first chapter.

A theoretical review of synchronous machine as a generator focus specifically to generate electricity, a modeling of this machine and the results of automatic voltage regulator are presented in the second chapter.

In the last chapter, our work will study the system of a diesel engine provide a mechanical torque to feed the generator and produce an electrical energy on open circuit using two regulator ones to control the speed which to fixed the frequency and another regulator to control a voltage of out the generator.

Chapter 1

Diesel engine: Generalities and modeling

I.1. Introduction

In this chapter, we have tried the basic knowledge related to spark ignition engines. We first briefly describe the structure of the engine as well as the functions and the main geometric characteristics of the basic mechanism. We then address the four-stroke thermodynamic cycle before defining the productivity and performance metrics of the theoretical cycle calculated from the Clapeyron diagram [1].

Additionally, we discuss the specific aspects of gasoline injection in a gasoline engine, from mixture formation to the reaction process.

The chapter ends with a description of the different polluting emissions from internal combustion.

For motorists or physicists who understand the phenomena associated with internal combustion engines, this chapter is only a reminder. It is intended more particularly for control engineers who wish to familiarize themselves with the fundamentals necessary for a better understanding of the operation of commanded speed engines [3].

I.2. General Information on diesel engines

The structure of a car engine is largely based on a block containing several individual combustion chambers. These chambers are delimited by the cylinder head, the cylinder and the piston. Due to combustion, the reciprocating linear motion of each piston drives the connecting rod-crank system, which provides the rotary motion of the crankshaft [4].

The performance of an engine depends above all on the energy released by combustion and therefore on the quantity and quality of the fuel mixture present in the combustion chamber. These are also directly related to the geometry of the engine compartment volume (unit displacement) and the number of engine compartments or cylinders (total displacement) [2].

Figure I.1: diesel engine.

In order to increase average power and reduce lost motion at different torque levels due to reciprocating piston motion, a multiple cylinder configuration is preferred. Depending on the arrangement of the cylinders, two types of multi-cylinder engines are used (Figure I.1): in-line cylinders or V-cylinders [1].

Figure I.2: different types of cylinders.

Most current production vehicles are equipped with engines with four or more cylinders.

I.3. Functional analysis

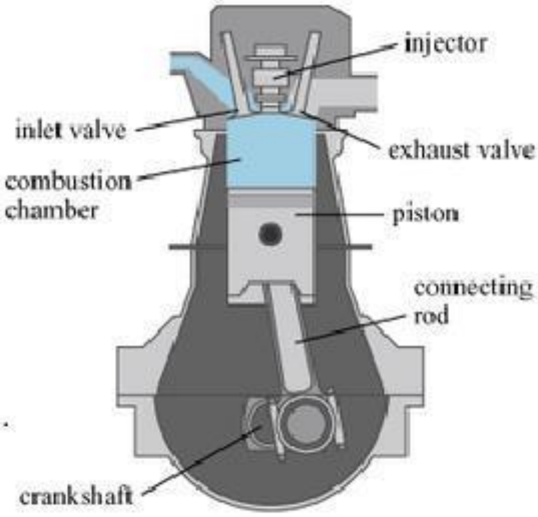


Figure I.3: function of the cylinder.

The operation of the heat engine is ensured by the union of four major functional groups [2]:

A- Systems with mechanical functions

1) The enclosure system: ensures the isolation of the gaseous mass.

2) The connecting rod-crank system: ensures the transformation of the alternating rectilinear movement of the piston into a rotational movement.

3) The timing system: controls the opening and closing of the valves in due time.

B- Auxiliary systems:

1) The lubrication system

2) The cooling system

3) The starting and charging system (electrical circuit) [2].

I.4 Principle of operation

We won't go into the specifics of the thermal engine's operation in this section; instead, we'll focus on its fundamental principles while paying extra attention to the control issues [2].

The following diagram can be used to visualize a commanded speed engine:

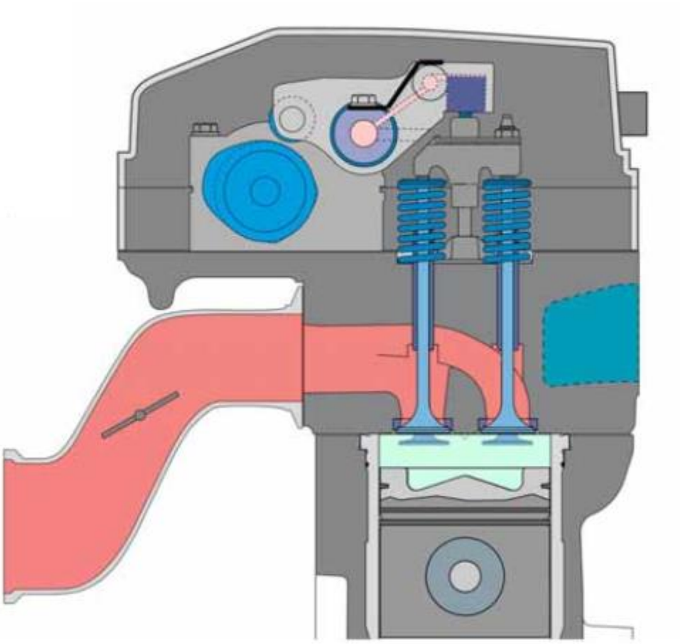


Figure I.4: Schematic diagram of a diesel engine.

The angle of the throttle valve and the back pressure (downstream pressure/upstream pressure) affect the flow rate of fresh air entering the manifold. Following that, an amount of exhaust gas from a prior combustion that cycles via the EGR valve is supplied. The intake manifold is then used to inject this mixture into the cylinder. In the case of indirect injection, the intake pipe from the manifold to the cylinder is where the air/diesel combination is created. In contrast, when using direct injection, the mixture enters the combustion chamber right away. At the conclusion of compression, the electronically regulated spark plug ignites the mixture. The pressure in the cylinder then rises as a result of the air-diesel combination burning. The piston moves linearly as a consequence of the pressure forces given to it; this linear movement is subsequently converted to rotational movement via a connecting rod-crank arrangement. The acquired burned gases are expelled through the exhaust line that connects to the catalytic converter after combustion [3].

Alphonse Beau de Rochas described the operational cycle of the reciprocating 4-stroke engine with controlled ignition in his autobiography in 1862. This engine was incorrectly referred to be an internal combustion engine since the mixture burns more gradually [4].

The cycle's function is to depict the work done by the system during each of the engine's four strokes. Every time, we shall depict the P.V. diagram of the actual cycle resulting from Beau De Rochas' labor. This cycle completes two rotations at 720° Crankshaft (0 V). Figure I.5 below shows the heat engine's four operational phases[2]:

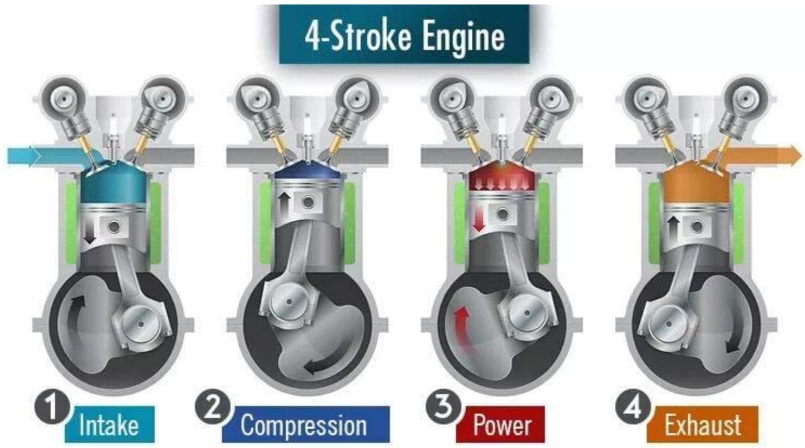


Figure I.5: Four stroke engine stages.

C- Intake: (0°V <θ<180° V)

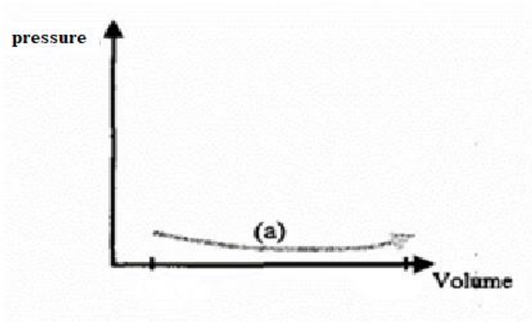
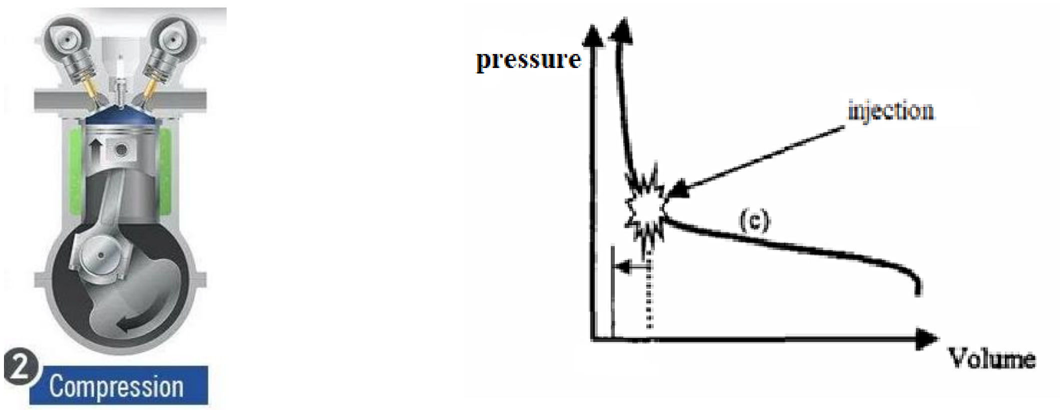


Figure I.6: Intake.

As the piston moves from TDC to BDC, generating vacuum in the cylinder, the intake phase happens. The theoretically intended entire filling of the cylinders is prevented by pressure dips in the intake circuit (throttle, valves, etc.) [2].

D- Compression: (180°V <θ<360° V)



FigureI.7:Compression.

The piston rises during the compression phase while the valves are closed; it is during this phase that the mixture ignites (often before top dead center), rapidly increasing the pressure in the chamber[2].

E- Power: (360°V <θ<540°V)

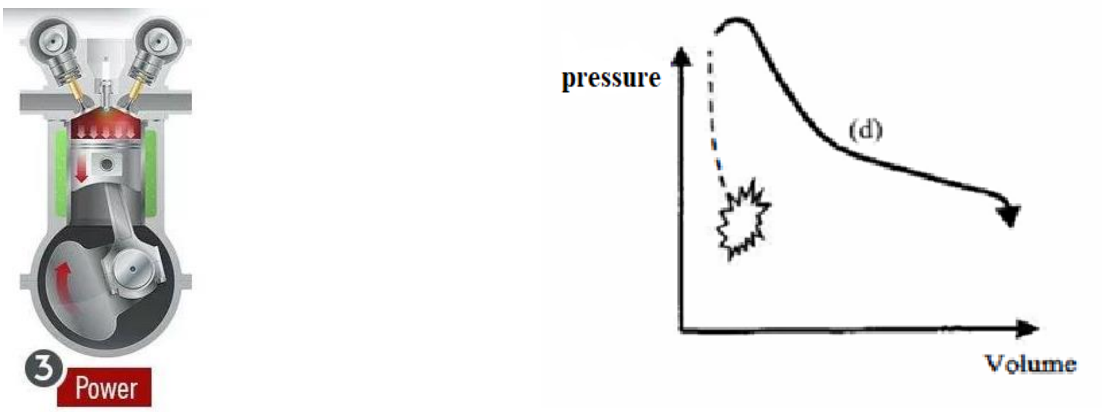


Figure I.8: Power.

The piston rises during the compression phase while the valves are closed; it is during this phase that the mixture ignites (often before top dead center), rapidly increasing the pressure in the chamber [3].

F- Exhaust: (540° V <θ<720°V)

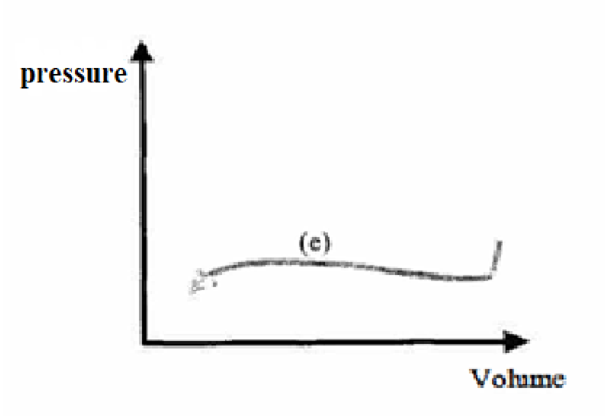


Figure I.9: Exhaust.

When the piston rises and the exhaust valve opens, the exhaust phase releases the burned gases. Due to the inertia of the gas transfer, optimal filling is accomplished by opening the intake valve before to TDC and doing the same with the exhaust valve after TDC, leaving them both open for a period of time known as "valve crossing."

I.5 Thermal engine characteristics

The characteristics of heat engines are given by several parameters which define the operation and performance of thermal engines. These basic parameters of a reciprocating engine are [3]:

I.5.1 Geometric parameters

G- Cylinder capacity:

The unit cylinder capacity V_c corresponds to the volume produced by a piston taking an L course [4].

$$V_c = \frac{\pi b^2}{4} . L \qquad \text{(I-1)}$$

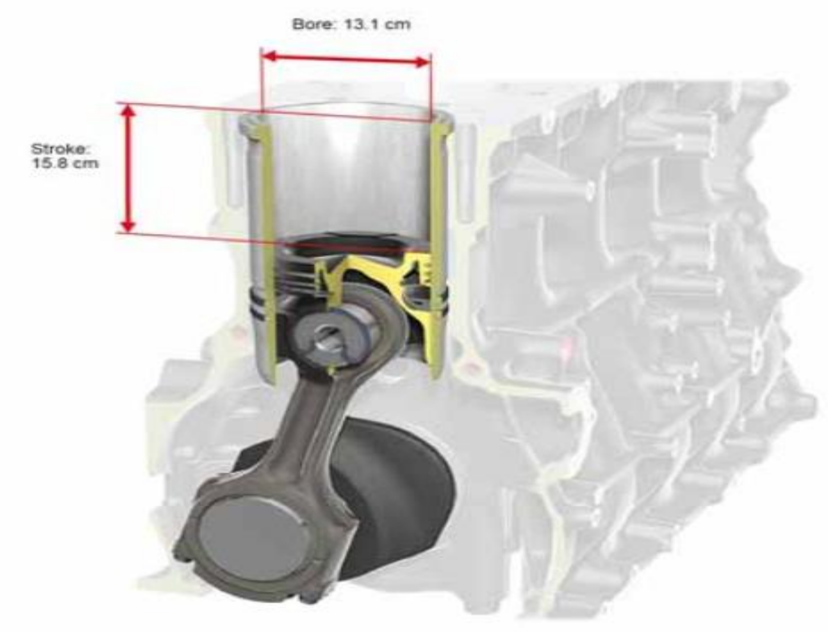


Figure I.10: The cylinder capacity

This volume, V_c is delimited by the walls (bore b) of the cylinder and the limits minimum and maximum piston excursion between top dead center (TDC) and point dead bottom (BDC).

The total displacement V_d of a heat engine is equal to the unit displacement multiplied by the number of cylinders n_{cyl}[1].

$$V_d = n_{cyl} V_c \qquad \textbf{(I-2)}$$

H- The compression ratio

Its value is between 14:1 and 25:1 for most thermal engine commanded speed its definition is as follows:

$$r_c = \frac{volume\ totale\ de\ cylindre}{volume\ mort\ de\ cylindre} = \frac{V_c + V_m}{V_m} \qquad \textbf{(I-3)}$$

The vacuum that persists between the cylinder head and the piston while the latter is at top dead center (TDC) is known as the dead volume (V_m) [1].

I.5.2 Efficiencies

I- Global efficiencies

Different partial efficiencies exist to describe the different energy losses namely /Heywood, 1988/:

- The loss due to unburned fuel is represented by the combustion efficiency η_{comb}.
- Theoretical thermodynamic cycle: theoretical thermodynamic efficiency η_{th},
- The difference between the actual cycle and the theoretical cycle is measured by the cycle efficiency, or "η_{cycle}"
- The organic efficiency η_{mec}, which is related to the mechanical losses from friction and the energy required to run the engine's necessary accessories.
- The sum of these individual efficiencies is equivalent to the total efficiency of a heat engine [1].

$$\eta_{global} = \eta_{comb} + \eta_{th} + \eta_{cycle} + \eta_{mec} \qquad \textbf{(I-4)}$$

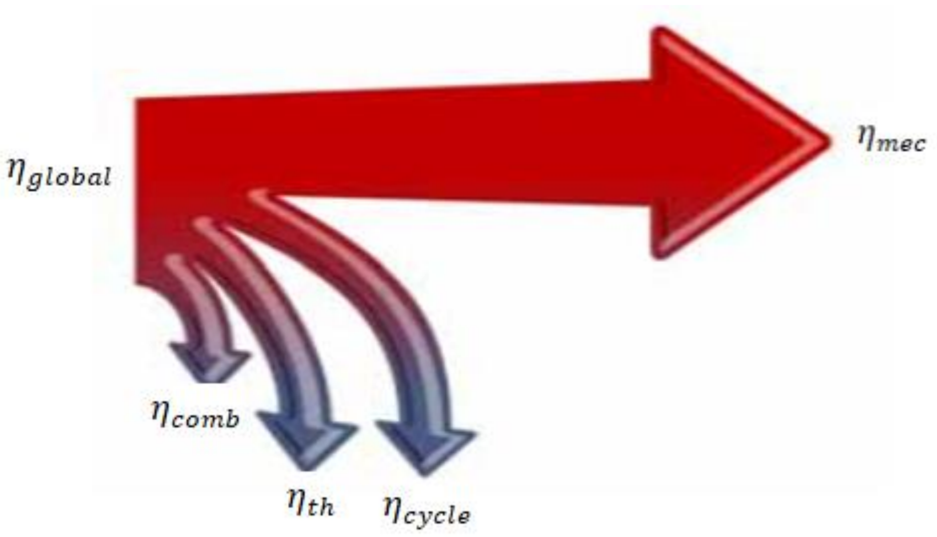


Figure I.11: The efficiency plan.

With all of these losses, the worldwide maximum yield is just around 35% at full throttle, compared to a somewhat higher yield for diesel engines (40%). Additionally, the work that is visible on the engine's crankshaft is not the actual work that propels a car forward since there are other losses at the transmission level to take into account [3].

J- Volumetric efficiency

The engines running at four times are a magnificence. It allows for the identification of cylinder losses in terms of charge owing to deflections brought on by various accessories (air filter, vane, heat exchanger located near entrance valves, etc.). One of the two relationships below can be used to describe the volumetric rendering [1]:

$$\eta_v = \frac{2\dot{m}_{cyl}}{\rho_{air} V_d N} \quad \textbf{(I-5)}$$

$$\eta_v = \frac{m_{cyl}}{\rho_{air} V_d} \quad \textbf{(I-6)}$$

ρ_{air} is the air density, m_{cyl} and $\dot{m}_{cyl}$ are the mass and the amount of air lost from a cylinder during each cycle, respectively, and N is the camshaft's rotational speed [1].

I.5.3 Specific fuel consumption

Specific consumption is a largeness that makes it possible to describe the engine's economic performance. Consumption Specific (SFC) is defined as a measurement of how effectively fuel's energy is converted into usable energy. /Heywood, 1988/:

$$sfc = \frac{\dot{m}_{cyl}}{P} \quad \textbf{(I-7)}$$

This coefficient allows for the definition of the essentiality conversion rate η_{diesel}, such as

$$\eta_{\text{diesel}} = \frac{W_c}{m_f Q_{\text{diesel}}} = \frac{P}{\dot{m}_f Q_{\text{diesel}}} = \frac{1}{csc Q_{\text{diesel}}} \quad \textbf{(I-8)}$$

m_f: is the diesel mass induced in the cylinders in one engine cycle.

Q_{diesel} : is the Energy constant of diesel [42,5 KJ/Kg.K]

I.5.4. A motor's output power

The previously discussed parameters allow for the definition of the thermal engine's performance in terms of power or couple. The following relationship illustrates the relationship between power and these several parameters [1]:

$$P = \frac{\eta_{\text{diesel}} m_{cyl} N Q_{diesel}}{n_R \left(\frac{\dot{m}_{cyl}}{\dot{m}_f} \right)} \qquad \textbf{(I-9)}$$

The number of spins per cycle is the constant n_R. She is equal to 2 for 4-speed engines. The relationship between the engine's power output and its cylinder is made apparent by include the volumetric performance in this relationship [2].

$$P = \frac{\eta_{\text{diesel}} \eta_v \rho_{air} V_d N Q_{\text{diesel}}}{2 \left(\frac{\dot{m}_{cyl}}{\dot{m}_f} \right)} \qquad \textbf{(I-10)}$$

This most recent relationship highlighted the significance of several parameters for optimizing engine performance. The volumetric and conversion performance, engine geometry, and air density all have a role in how the couple (or power) changes with time [1].

I.5.5 The air filling rate

It is the ratio between the amount of air that is actually let in and the amount that is theoretically allowed between the TDC and BDC in the cylinder at 20°C and 1 bar (normal circumstances). The piston's extreme places within the cylinder are TDC and BDC.

In a classic engine without variable valve timing, the filling is mapped according to the regime N_e and the manifold pressure P_{col} [3]:

$$\eta_{vol} = f(N_e, P_{col}) \qquad \textbf{(I-11)}$$

I.5.6 The richness of the mix

The primary characteristics of the AC engine are found in its alimentation and combustion modes. In fact, the engine is fed with an air-fuel mixture that is prepared either before being introduced into the cylinder (indirect injection) or inside the cylinder (direct injection). The amount of air let in is controlled by a flap (the butterfly) in the entry tube, and the fuel is dosed by an injection system. The "richness of the mixture" is the mass ratio between fuel and combustibles that is given by [2]:

$$\lambda = \frac{m_{fuel}}{m_{air}} \lambda_s \qquad \textbf{(I-12)}$$

Where λ_s is the stoichiometric ratio which represents the mass of air m_{air} necessary for the stoichiometric combustion of the unit mass of fuel m_{fuel}:

$$\lambda_s = \left(\frac{m_{air}}{m_{fuel}}\right)_{\text{stoechiometric}} \qquad \textbf{(I-13)}$$

The combustor power of a hydrocarbure is approximately 14.67 grams of air for every gram of fuel. Therefore, combustion is said to be stoichiometric if λ=1.

A mixture of wealth that is greater than 1 will be referred to as wealthy, while one that is less than 1 will be called poor. Riches have a significant impact on pollution emissions, as seen in Figure I.10 every pollutant needs to be subject to a wealth compromise [1].

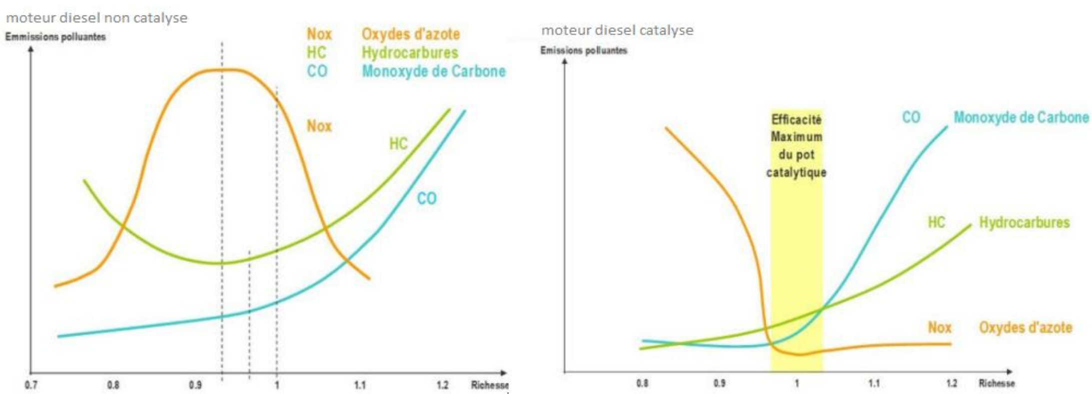


Figure I.12: Taux de polluants en fonction de la richesse.

I.5.7 Energy balance

A Clapeyron graphic is frequently used to illustrate the four-times cycle. This graphic, shown in Figure I.11, shows how the pressure of cylinder-filling gases changes with temperature. The admittance of gas proceeds from g to b via a. The development of gas compression occurs from B to C. There is combustion from c to d, followed by gas release from d to e. The escape is produced in n from e to g through f. The working surface for gases is defined by the curve of pressure evolution as a function of volume. The surface A (Orange) on Figure I.10 corresponds to the high-pressure balloon and represents the work done by the engine [1].

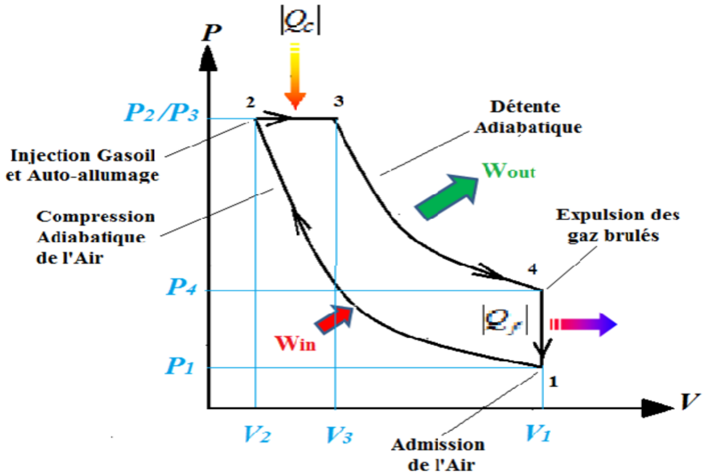


Figure I.13: Clapeyron's theoretical diagram of pressure versus volume.

K- The indicated work W_i of the motor:

$$W_i = -\oint_{cycle} P_{cyl} dV_c \qquad \text{(I-14)}$$

Where P_{cyl} and V_c stand for the cylinder's pressure and volume, respectively. Conventionally, the work is negative when the engine produces the work since it is destroyed by the system (as seen from the side gas). The work will thereafter be viewed as positive when the energy in the gas is depleted and as negative when losses are involved (as seen from the camshaft side). This work is referred to as indicated since it was measured for the first time by Watt on a steam engine using an indicator of Watt manometer. When pressures are expressed in Pascal (P_a) and volumes in meter cubic (m^3), it is expressed in Joules (J) [3].

To compare the performance of different engines, the concept of Indicated Mean Pressure (IMP) is introduced:

$$IMP = \frac{1}{V_{cyl}} \oint P_{cyl} dV_d = \frac{W_i}{V_{cyl}} \quad \textbf{(I-15)}$$

Where V_{cyl} is the displaced volume of the cylinder, the displacement. It represents the constant pressure that would have to be applied to the piston to obtain the indicated work W_i [2].

From the indicated work W_i, the indicated torque C_i is defined by:

$$C_i = \frac{W_i n_{cyl}}{4\pi} = \frac{PMI n_{cyl} V_{cyl}}{4\pi} \quad \textbf{(I-16)}$$

Where n_{cyl} is the number of cylinders [4].

The effective torque C_e, actually delivered by the shaft and measured on the engine bench, is determined by:

$$C_e = C_i - C_{frot} \quad \textbf{(I-17)}$$

Where C_{frot} is the friction couple. On the engine bench, C_{frot} is deduced from the measurement of C_e and C_i [4].

By analogy with the IMP, from (I.17), the Effective Mean Pressure (EMP) is defined:

$$PME = \frac{C_e 4\pi}{n_{cyl} V_{cyl}} \quad \textbf{(I-18)}$$

Finally, the Friction Mean Pressure (FMP) is characterized by the relationship:

$$FMP = IMP - EMP \quad \textbf{(I-19)}$$

I.6 Injector excitation system

The purpose of the injection's excitation is to generate a quantity of heat with enough energy to cause the gas mixture to combust at the end of compression.
The injection of fuel causes this irritation [4].

L- Injector excitation order

There are two alternative orderings for the 4-cylinder inline engine: 1-4-2-6-3-5 For reasons of better gas fluid evaporation, the most commonly used order of illumination is the first one [4].

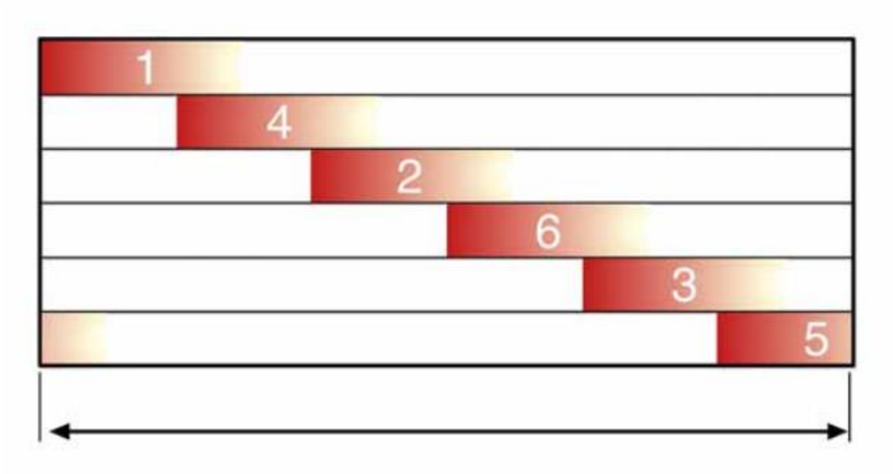


Figure I.14: Injection order of a 6-cylinder in-line engine.

M-Advance to injection excitation

The regime, mixture quality, and cylinder filling all affect the combustion's duration and time till ignition. This justifies the need to adjust the point of illumination relative to the engine cycle in order to maximize performance.

A little before the piston reaches the TDC, during the mixture's compression phase, the angle between the camshaft tree's location at the point of ignition and its position at the TDC then represents the piston's position (Figure I.12) [1].

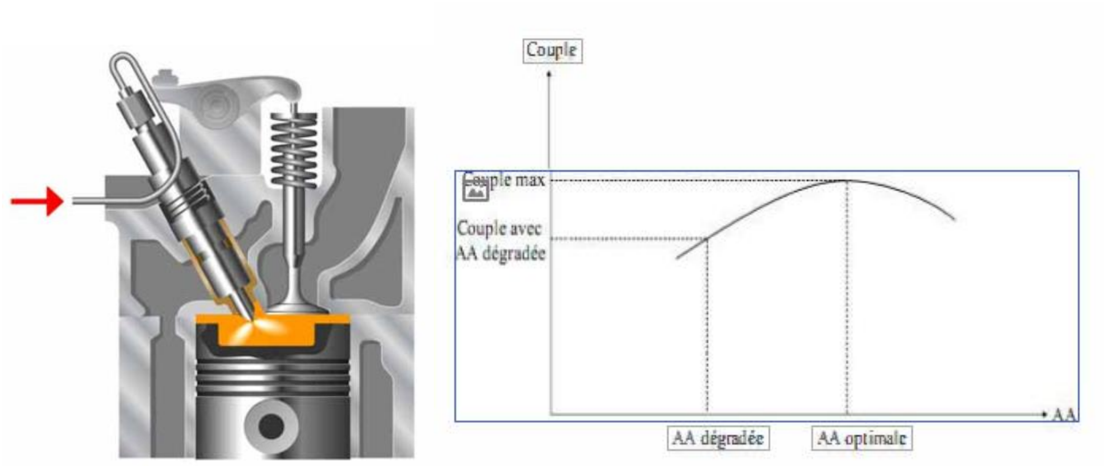


Figure I.15: Definition of the reference in degrees and Torque according to the injection excitation advance for a conventional engine

I.7. Diesel injection

Injectors have taken the place of carburetors because they provide better fuel pulverization and more precise control over the amount of fuel injected. The primary components of the fuel supply system are a reservoir, a pump, a ramp shared by the injectors, and an injection system. Fuel is injected into the cylinder head when using indirect injection engines. Injection is referred to as mono point if there is just one injector for the whole engine's cylinders (the injector discharges into a single common pipeline to all of the engine's cylinders). The injection is referred to as multipoint if there is one injector per cylinder. When using direct injection engines, the cylinder is directly injected with fuel [3].

In all cases, diesel injection requires management:

• The pressure in the injection rail,

• The injection phasing (period of the engine cycle when the injection occurs).

• The injection time, which fixes the quantity of fuel injected, for a given pressure [5].

The characteristic of the injector in relation to the injector's time of opening (t_{ing}) and injector pressure (P_{inj}) provides the amount of fuel injected (m_{inj}). The mass of fuel to inject may be calculated using the richness indicator, the amount of air injected per engine cycle and per cylinder, and the stoichiometric ratio of air to fuel, which for a diesel engine is equal to about 14.67[1].

$$m_{inj} = \frac{m_{air}}{\lambda_s}.\lambda \qquad \textbf{(I-20)}$$

If the injection is indirect, it usually happens before air is admitted (Figure I.13). The delay is lessened with direct injection but is still significant (between 2 and 3 TDC), mostly because of the control system. In order to effectively control the amount of wealth in the cylinder, the air volume must be predicted [5].

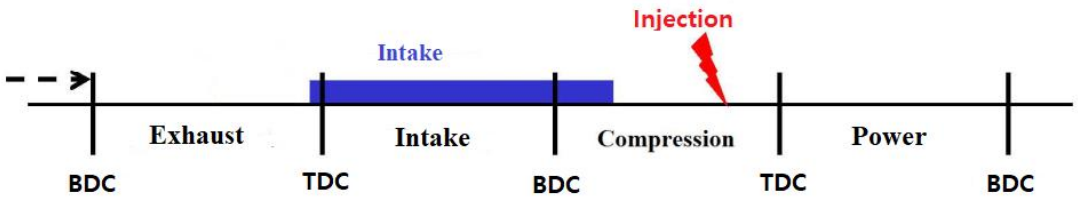


Figure I.16: Injection sequence in the cycle for an indirect injection engine.

I.8. The direct injection engine

The principle of the direct-injection engine has been known for a while, and it may reduce the engine's consumption by up to 15%. The engine will operate in two distinct modes: the homogeneous mode, which is similar to how today's injection-based engines operate, and the stratified mode, where the consumption gains are greatest. This is in addition to the fact that the phenomenon of parois growth has been eliminated, making the dosage of the fuel much more precise [14].

I.8.1. The homogeneous mode

The homogeneous approach entails injecting the diesel at the admissions phase. The air/diesel mixture is distributed evenly throughout the combustion chamber. In this mode, one will essentially operate in a stoichiometric mixture, where the amount of fuel to inject depends on the amount of air that is allowed.

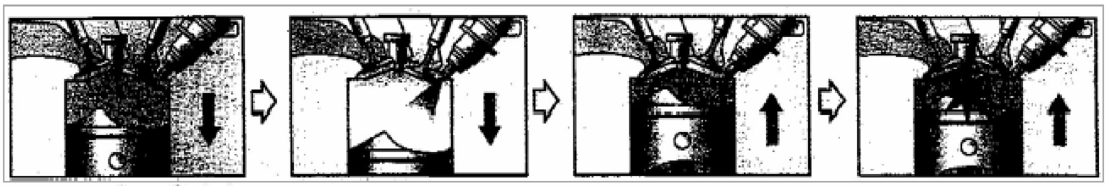


Figure I.17: operation in homogeneous mode, injection during the intake phase.

I.8.2. The stratified mode

In contrast to the previous example, the injection will take place during the compression phase. The precise injection time is chosen in such a way that the introduced diesel is not distributed evenly throughout the cylinder.

In stratified mode, the air intake vannel is completely open, resulting in a very poor mixture right before ignition. The combustion will still occur because the combustion circumstances are close to the stoichiometry at the level and due to the specific shape of the piston [11].

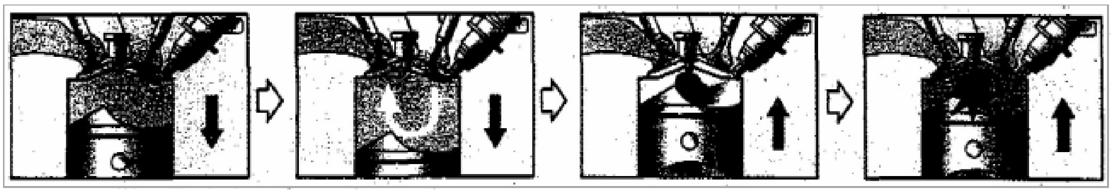


Figure I.18: operation in stratified mode, injection during the compression phase.

I.9. Emission of pollutants

One of the primary concerns of builders nowadays is the reduction of polluting emissions in order to meet more stringent regulations. Carbon dioxide (C02) is an unavoidable byproduct of combustion that contributes to the effect of smog and whose production must be limited, in large part by limiting vehicle consumption. On a car, there are three sources of pollution [10]:

- The exhaust gas
- Diesel vapors, mainly from the fuel tank
- Crankcase gases, made up of oil and diesel vapors

The complete burning of a hydrocarbure produces water vapor (H20), carbon dioxide (C02), nitrogen (N2), and sulfur dioxide (S02) (toxic but emitted in very small amounts).

In addition to these compounds, there are families of pollutants whose production is regulated by the standards.

- Carbon monoxide (CO)

• Unburnt hydrocarbons (HC)

• Nitrogen oxides (NO, NO_2) commonly called NO_x

The previous Figure I.10 depicts the production curves of these pollutants in ppm (particulars per million) as a function of the mixture's richness. This curve was obtained for a homogeneous operation; the poor limit is undoubtedly much lower for a stratified operation.

Let us now summarize the factors that influence their manufacture [12].

I.9.1 Unburnt hydrocarbons (HC)

La production des HC, comme son nom l'indique, est directement dépendante de la qualité de la combustion. En effet, si l'on an un excès de carburant (richesse>l), on va favoriser leur production. Au contraire, leur minimum de production correspond à un mélange relativement pauvre (0.8). Au-delà de cette limite, en fonctionnement homogène, d'autres phénomènes apparaissent car les conditions de combustion se détériorent : les difficultés de propagation ou l'extinction prématurée de la flamme, voire l'absence de combustion, contribuent à créer une augmentation rapide de la concentration de HC. La croissance des HC en mélange riche s'explique naturellement par le manque d'oxygène [15].

I.9.2 Carbon monoxide (CO)

The generation of CO, like that of HC, increases with the richness of the mixture. Incomplete carbon oxydation is caused by a lack of oxygen, and the presence of these two compounds indicates incomplete combustion. Thus, the engine output (Figure I-10) corresponds to a minimum production of these two pollutants [9].

I.9.3 Nitrogen oxides (NOx)

The occurrence of azote oxydes (NO and NO2) is, however, dependent on the evolution of the temperature-oxygen concentration parameters.

The relatively poor mixtures (richessO.8) promote an increase in temperature in the cylinder and hence represent the most favorable circumstances for NOx generation [8].

I.10 Depollution

As shown in Figure I.10, the greatest of HC and CO production corresponds to the maximum of NOx generation. As a result, natural engine depollution (uniquely by adjusting its operating point) is unachievable with current antipollution standards. This is why, for the past few years, a catalytic converter has been required in the evaporation line. This device allows for redox, which allow for the reduction of NO and the oxidation of HC and CO. The catalytic pot has the disadvantage of having to work with a stoichiometric mixture despite its high efficiency. On the one hand, this does not correlate to the maximum engine output, and on the other hand, it necessitates extremely precise wealth regulation [8].

I.11. Engine modeling

The modeling of internal combustion engines is presented by considering the following functional breakdown:

• The air admission function combines the modeling of the various gas flows admitted into the cylinders.

• The essence injection function encompasses the modeling of the diesel from the injector's output to the cylinder.

• The combustion function, which contains the models of the variables that characterize combustion (Due to the complexity of this model, empirical laws were chosen for combustion modeling).

• The dynamic function of the camshaft combines the models of the engine's mechanical portion that express the conversion of combustion energy to mechanical energy [6].

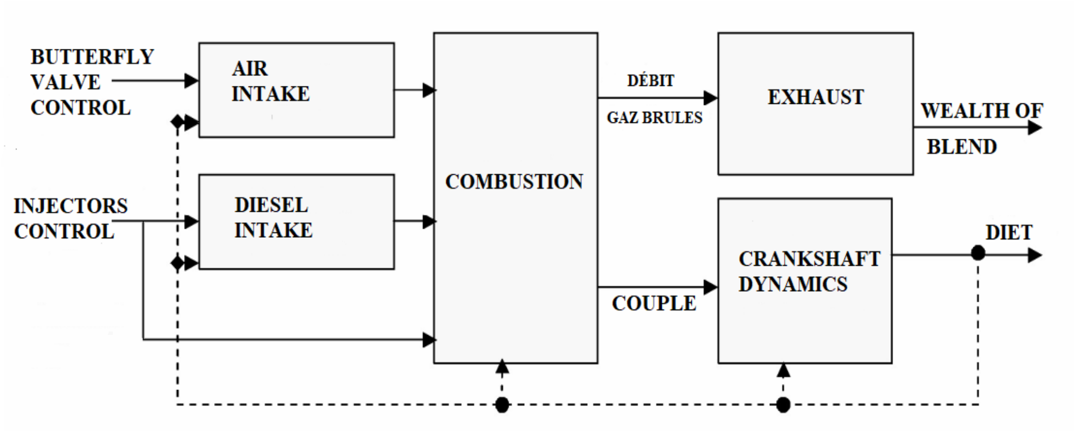


Figure I.19: Functional diagram of a heat engine (diesel).

The problem with this model is that the thermal engine is a complicated, multidisciplinary, non-linear, fast system with saturations of actioners. Furthermore, many significant physical dimensions are not measured, and their modeling is difficult. To solve this problem, we must consider certain simplified hypotheses, which are summarized below:

• The gases are assumed to be perfect;

• There are no spatial variations in pressure or temperature within the control volumes;

• The model does not account for the exact geometry of the admission and exit conduits; each open system is represented by its average volume; and

• The pressure and temperature limits of the system are assumed to be equal to the ambient conditions.

• The effects of thermal transfer to collector parois are overlooked.

• Mono dimensional compression of perfect compressible gases.

• The conservation of mass and energy [1].

I.11.1 Air intake subsystem

The block diagram of the air intake system is shown in figure (I.16). It includes the following components:

• The butterfly of gas that commands the air debit [1].

• The entrance collector and its extensions in the clause that distributes air to the four cylinders.

• Admission valves that synchronize the entry of fresh mixture into the cylinders [7].

The entry angle is ϕ_{pap}, and the exit mass is the amount of air admitted to the cylinder during the admission phase [7].

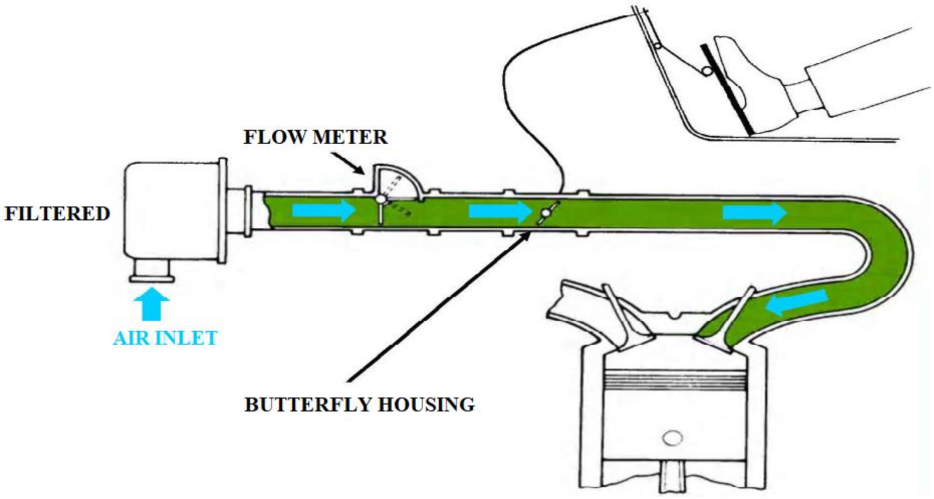


Figure I.20: Diagram of the fresh air intake circuit.

In this case, air is regarded as the ideal gas. The air admission circuit is made up of many components (figure III.3), which are: the air filter at the admission entrance, the limitations at the level of the butterfly, the admission collector, and the admission valves located at the entrance of the cylinders [6].

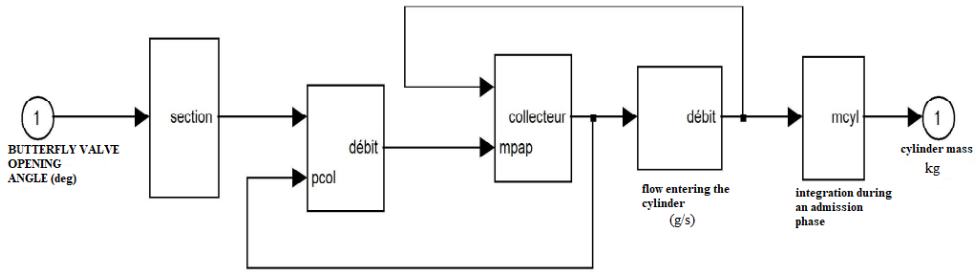


Figure I.21: Block diagram of the air intake system.

a. Model of the airflow through the butterfly valve

This model is based on the description of the mass transfer of a compressible fluid via a limitation, with the assumption that air flow is unidirectional. (The inlet pressure is assimilated to the atmospheric pressure, which amounts to neglecting the pressure drop of the air filter).

The model's entries/sorties, as well as the various parameters, are shown in Table **I.21**.The following is the form of the relationship [3]:

$$m^{\cdot}_{pap}(t) = C_d \frac{p_{am-pap}(t)}{\sqrt{RT_{am-pap}(t)}} S_{res}\left(\phi_{pap}\right) g\left(P_r(t)\right) \qquad \textbf{(I-21)}$$

$P_r(t)$: represents the ratio between the pressure downstream of the butterfly valve, which is the pressure in the intake manifold, and the pressure upstream of this butterfly valve [1].

Inputs	$P_{am\text{-}pap}$	Pressure upstream of the butterfly valve (Pa)
	$T_{am\text{-}pap}$	Temperature upstream of the butterfly valve (°K)
	P_{col}	Pressure in the intake manifold in (Pa)
	ϕ_{pap}	Throttle opening angle (%)
Outputs	$\dot{m}_{pap}$	Air mass flow through the butterfly valve ($Kg.s^{-1}$)
Settings	C_d	The head loss coefficient
	γ	Specific heat ratio for air

Tableau I.22: Restriction model inputs/outputs/parameters of the butterfly valve.

The functions S_{res} (ϕ pap) and g(P_r) are two non-linear functions that we

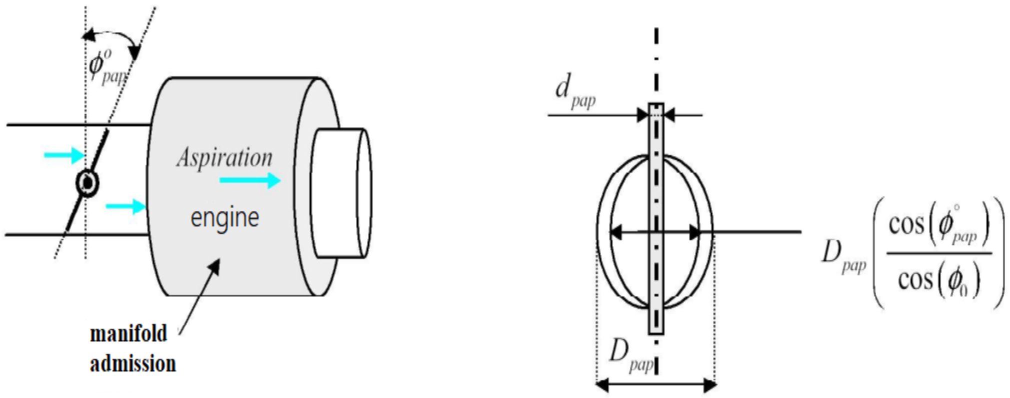


Figure I.23: Butterfly valve geometry.

will discuss. In the case of a natural aspiration engine, the pressure in front of the butterfly is considered equal to atmospheric pressure [2].

$$S_{res}(\dot{\phi}_{pap}) = \frac{\pi D^2{}_{pap}}{4}\left(1 - \frac{\cos(\dot{\phi}_{pap})}{\cos(\phi_0)}\right) \qquad \textbf{(I-22)}$$

The variations of C_d and $S_{res}(\phi_{pap})$ are, in general, grouped together in the same function called the effective opening surface of the butterfly.

$$S_{eff}(\dot{\phi}_{pap}) = C_d S_{res}(\dot{\phi}_{pap}) \qquad \textbf{(I-23)}$$

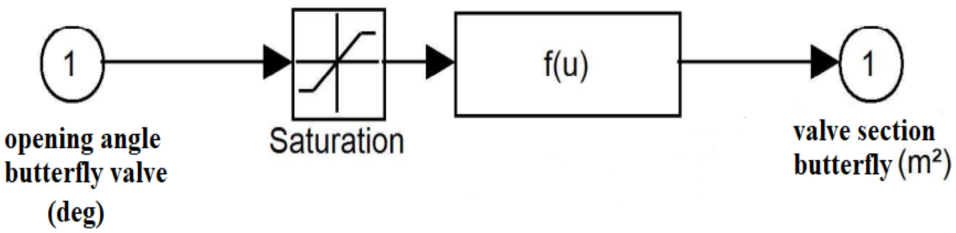


Figure I.24: Butterfly valve opening section

The continuous nonlinear function $g(p_r)$ is defined by the Barré St from equations as follows [1]:

$$g(P_r) = \begin{cases} \sqrt{\frac{2\gamma}{1+\gamma}}(p_r)^{\frac{1}{\gamma}}\sqrt{\left(1-(p_r)^{\frac{\gamma-1}{\gamma}}\right)} & ,si\ p_r > \left(\frac{2}{1+\gamma}\right)^{\frac{\gamma}{\gamma+1}} \\ \sqrt{\gamma}\left(\frac{2}{1+\gamma}\right)^{\frac{\gamma+1}{2(\gamma+1)}} & ,si\ p_r > \left(\frac{2}{1+\gamma}\right)^{\frac{\gamma}{\gamma+1}} \end{cases} \quad \textbf{(I-24)}$$

The parameter y represents the relationship between specific heat at constant volume and specific heat at constant pressure (for air, $\gamma = 1.4$).

Another way to express the airflow via the butterfly valve, as seen in the illustration (III.7) [1]:

$$m^{\cdot}_{pap} = f(\phi)g(p_r) \quad \textbf{(I-25)}$$

Avec:

$$f(\phi) = 2.821 - 0.05231\phi + 0.10299\,\phi^2 - 0.00063\,\phi^3$$

$$g(P_r) = \begin{cases} 1 & si\ \ p_r \le \frac{p_0}{2} & sonic\ flow \\ \frac{2}{p_0}\sqrt{p_r p_0 - {p_r}^2} & si\ \ p_r > \frac{p_0}{2} & sup\ sonic\ flow \end{cases} \quad \textbf{(I-26)}$$

With: *f(ϕ)* is the opening section of the butterfly valve and g (P_r) the function no continuous linear.

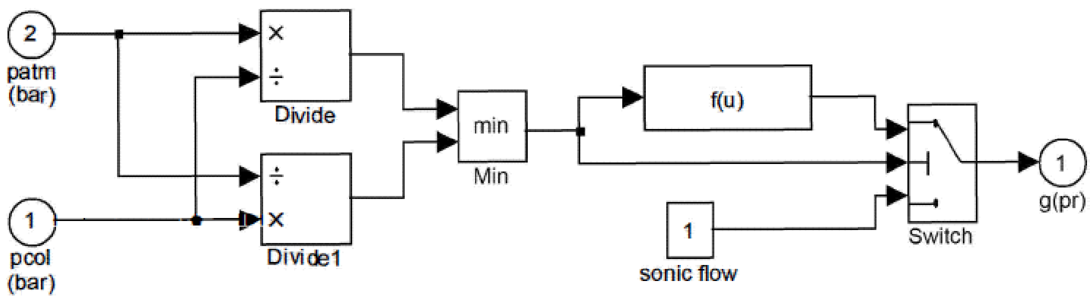


Figure I.25: Simulation diagram of the continuous nonlinear function g(p_r).

b. Model of the average flow of air admitted into the cylinders

The power provided by a combustion engine is mostly determined by the air filling of the cylinders that condition the injection of diesel. The term "pumping" (natural aspiration) refers to the quick movements that occur during the opening of the valve, as well as the non-uniform movement of the piston, which causes acoustic phenomena (pressure wave to obtain resonances that improve the filling of the engine at specific conditions) [2].

The amount of money entering the cylinders is calculated as a function of the collector pressure (P_{col} in bar) and the engine speed (N_e in trs/min).The following relationship gives the formula for the total debit entering the cylinders (m_{cyl} in kg/s):

$$\dot{m}_{cyl}(Ne, P_{col}\ ) = \frac{V_d}{120RT_{col}} N_e \eta_v (N_e, P_{col}) P_{col} \qquad \textbf{(I-27)}$$

For another model the average flow rate of air admitted into the cylinders is given by the following equation:

$$\dot{m}_{cyl} = -0.366 + 0.008979N\ P_{col}\ - 0.0337\ N\ {P_{col}}^2\ + 0.000IN^2 P_{col} \qquad \textbf{(I-28)}$$

Where V_d is the total engine displacement, N_e is the average engine speed in revolutions per minute, η_v (N_e, p) is the volumetric efficiency, T_{col} the temperature in the collector [1].

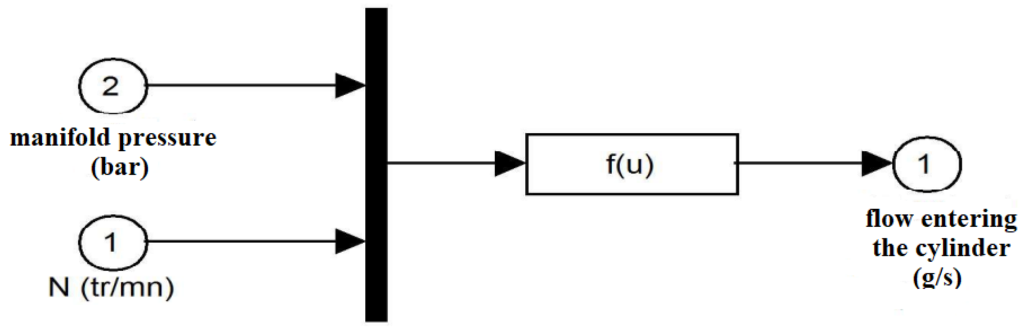


Figure I.26: Simulation diagram of air flow admitted into the cylinders

c. Model of the pressure in the air intake manifold

The intake manifold, whose volume varies according to engine displacement, has an effect capacitive on flow due to pneumatic inertia as explained below [5]:

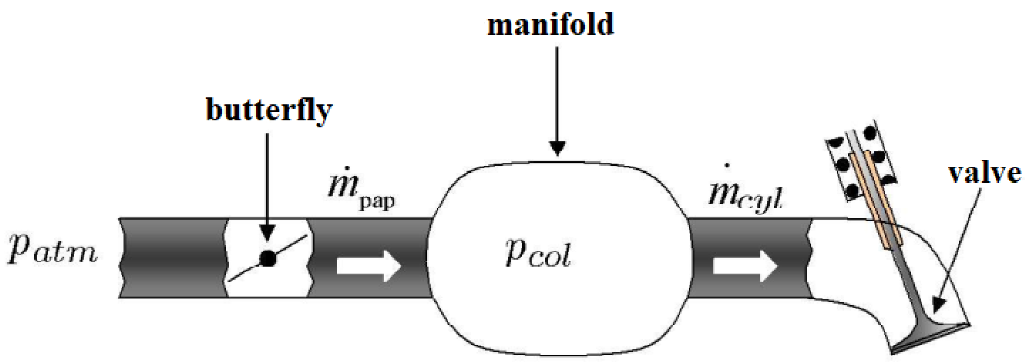


Figure I.27: Intake manifold diagram

If we consider an enclosure filled with a compressible fluid comprising orifices input and output with the following assumptions:

• Uniform pressure.

• Presence of diesel (mass, vaporization) neglected.

• Constant temperature.

• Negligible friction.

• Sections of the holes is small compared to the dimensions of the enclosure [5].

The dynamic of pressure in the air intake collector is described by a nonlinear differential equation of the first order (I-29), which is a function of the air butterfly (entrant) debits $\dot{m}_{pap}$ and the mass of air injected into the four cylinders $\dot{m}_{cyl}$ (outgoing) [3].

$$\dot{P}_{pol} = \frac{RT_{col}}{V_{col}}\left(\dot{m}_{pap} - \sum_{i=1}^{n_{cyl}} \dot{m}_{cyl_i}\right) + P_{col}\frac{\dot{T}_{col}}{T_{col}} \qquad (\mathbf{I-29})$$

Where T_{cal} is the temperature inside the intake manifold, considered equal to the temperature upstream of the Tam pap butterfly valve. The constant Vcal is the volume of the collector and R the ideal gas constant and the sum of the cylinder flow rates $\dot{m}_{cyl} = \sum_{i=1}^{4} \dot{m}_{cyl}$

The second part in (III.30), which contains the temperature derivative, is sometimes overlooked when considering the hypothesis that temperature fluctuations are relatively slow in comparison to other variables in play (pressures, actionneur locations, etc.) [11].

$$\dot{P}_{pol} = \frac{RT_{col}}{V_{col}}\left(\dot{m}_{pap} - \sum_{i=1}^{n_{cyl}} \dot{m}_{cyl_i}\right) \qquad (\mathbf{I-30})$$

As a result, the model isotherm exhibits a greater error during the quick transits of the butterfly valve than the model adiabatic, which takes temperature dynamics into account [1].

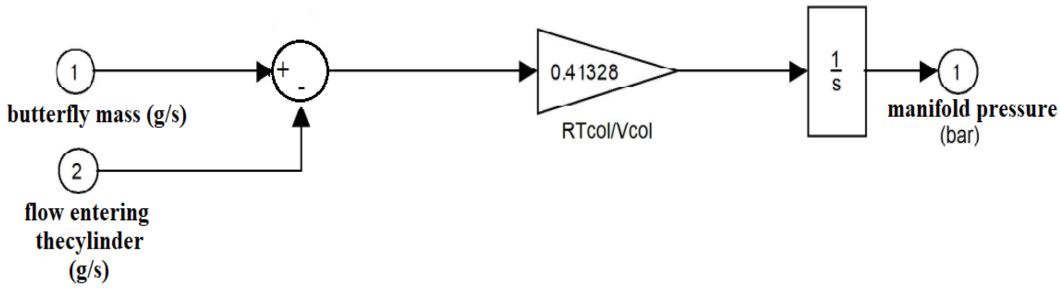


Figure I.28: Manifold pressure simulation diagram

I.12 Diesel dynamics model

One of the major elements in optimizing engine performance in terms of fuel consumption and pollutants is diesel injection in spark ignition engines.

For the past two decades, automobile manufacturers and suppliers have never stopped improving injection systems with the primary goal of lowering consumption. Today's gas-powered vehicles are virtually all equipped with multipoint indirect injection (MPI) systems, which have mostly superseded carburetors [3].

I.12.1 Principle of operation

In gasoline injection, air is introduced through a powerful intake pipe section, and fuel is injected upstream closer to the intake valve (indirect injection) or directly in the cylinder (direct injection). The injection might be mechanical or electronic, and it can be continuous or discontinuous [2].

I.12.2 Advantages of the injection system

The following are the key benefits of the injection system:

• Improved engine performance (torque, power, etc.).

• Fuel savings due to highly accurate dosing.

• Lower toxic emissions (better combustion).

• Improved cylinder air filling...

I.12.3 Different injection systems

Injection systems are classed based on where the fuel is injected into the air pulled in by the engine: direct injection occurs in the combustion chamber of the cylinder, while indirect injection occurs in the manifold intake, more or less near to the intake valve [3].

Injection systems can also be distinguished by the type of regulatory device employed. Mechanical injection uses a pump that is mechanically operated by the engine to pressurize diesel and meter the injected volume.

In electronic injection, on the other hand, an electric pump transports the pressurized fuel; the dosage, regulating, and injection functions are entirely or partially controlled by an electronic control unit.

In the case of this final sort of injection, the most often used models in the literature take wetting into consideration. The latter is due to a portion of the injected gasoline being deposited on the intake pipe wall prior to joining the cylinder, as seen in Figure I.24[1].

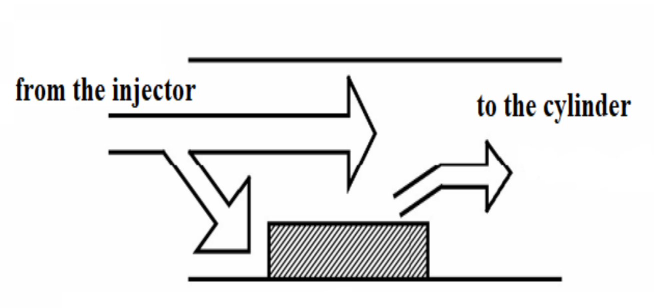


Figure I.29: Wall wetting phenomenon

The injectors are controlled by two parameters: start firmt injection (in crankshaft angle) and injection duration for each injector.

The amount of diesel to be injected into the cylinder of a diesel engine with multipoint indirect injection is dictated by the richness (A) intended for the mixture [4].

The diesel dynamics model is given by the following system of equations:

$$\begin{cases} \dfrac{dm_{ff}(t)}{dt} = \dfrac{1}{\tau_f}\left(-\dot{m}(t) + x\dot{m}_{fi}(t)\right) \\ \dot{m}_{fv}(t) = (1-x)\dot{m}_{fi}(t) \\ \dot{m}_f(t) = \dot{m}_{fv}(t) + \dot{m}_{ff}(t) \end{cases}$$

With $\dot{m}_f(t)$ the mass flow of diesel admitted into the cylinders, $\dot{m}_{ff}(t)$ is the flow mass of diesel in liquid form, $\dot{m}_{fv}(t)$ is the mass flow rate of diesel in vapor form and $\dot{m}_{fi}(t)$ flow rate of injectors.

• The λ_{cyl} richness (t) of the fuel mixture is given by the following equations [1]:

$$\lambda_{cyl}(t) = \frac{\dot{m}_{cyl}(t)}{\lambda_s \dot{m}_f(t)}$$

$$\dot{\lambda}_{cyl} = -\frac{1}{\tau_s}\lambda(t) + \frac{1}{\tau_\lambda}\lambda_{cyl}(t - \tau(N_e))$$

With $\lambda s = 14.67$ is the air/fuel ratio at stoichiometry, $\lambda(t)$ is the richness measured (lambda probe), τ_λ, is the time constant of the probe and τ (Ne) is a variable delay.

The reaction of diesel and air during combustion in a controlled ignition engine. The entire mass is kept when they are burned. The products of this reaction are shown below when the diesel $C_aH_bO_c$ reacts stoichiometrically with air $O_2 + 3.77\ N_2$[3].

$$C_aH_bO_c + \left(a + \frac{b}{4} + \frac{c}{2}\right)(O_2 + 3.77\ N_2) \rightarrow aCO_2 + \frac{b}{2}H_2O + 3.77\left(a + \frac{b}{4} + \frac{c}{2}\right) N_2$$

The ratio of air mass to fuel mass $\left(\frac{A}{F}\right)_s$ l is given in the case general by the following formula [1]:

$$\left(\frac{A}{F}\right)_s = \frac{\left(a+\frac{b}{4}+\frac{c}{2}\right)(2*15.9994+2*3.77*14.0067)}{a*12.011+\mathrm{b}*1.008+\mathrm{c}*15.9994}$$

For $C_{15}H_{32}$ (currently the most widely used fuel in diesel engines):

$$\left(\frac{A}{F}\right)_s = 14.67$$

The performance, emissions, and engine consumption are all influenced by this richness; for example, see figure I.24, which also shows the air intake structures and diesel in the cylinders [1].

Effectively, based on this data, the specific minimum consumption occurs around a wealth value of 0,9 where azote pollution emissions are at their highest. Around a wealth of 1,1 is where the maximum power is located. However, the catalytic pot technology has limited wealth to 15%. In fact, if one deviates from this value, the catalyst quickly degrades and loses a great deal of its effectiveness [6].

I.13. Combustion model

The fundamental phenomenon in controlled injection engines is combustion. She actually regulates the engine's power output, heat transfers to the foliage, and pollutant production. A precise and thorough explanation of this process at a fundamental level is not possible with the available tools. In particular, it is quite challenging to quantify pollutant production [6].

I.13.1 Principe de la combustion

Combustion obviously depends on the geometric characteristics of the engine such as the dimensions of the cylinder or the compression ratio. It also depends on following variables:

• The advancement of the illumination, which modifies the coupling since the compression forces acting on the cylinder are not the same. The best torque advance is known as the MBT (Maximum Best Torque),

• The combustion performance is influenced by the mixture's richness. This last one is the maximum for a mixture with a wealth of 0,9, but the wealth is kept at 1 for the previously mentioned reasons.

The pair motor's statistical model is then obtained by using a linear regression framework that involves the interaction of various variables and combinations of those variables [5].

The variables are shown in the following table:

Inputs	N_e	crankshaft rotational speed (tr/min)
	m_{cyl}	mass of air in the cylinder (kg)
	δ_{av}	angel of injection (º)
	λ	richness of air-diesel mixture measured at the exhaust (%)
Outputs	C_m	average engine torque (Nm)

Tableau I.30: Motor torque model inputs/outputs/parameters

I.14. Crank Connecting Rod Dynamics Model

The crankshaft is the crank that generates rotation from the piston's reciprocating motion and gets force from the connecting rod. The crankshaft couple, which is located at the end of this one in the shape of an engine couple, is subject to the force applied by the connecting rod.

The vehicle is propelled by the engine's torque at one end of the crankshaft. On the other end, a portion of the available torque is used to power the engine's auxiliary components, such as the air conditioning compressor, electric generator (dynamo or alternator), and timing (camshaft, valves, etc.) [8].

I.14.1 Cinematic calculation

M-Piston displacement calculation

$$X(\theta) = r.\left(1 - \cos\theta + \frac{\mu}{4}.(1 - \cos 2\theta)\right)\ en[m]$$

µ: the crank connecting rod manufacturing factor

$\mu = r/L_B$

r: crankshaft radius.

LB: connecting rod length.

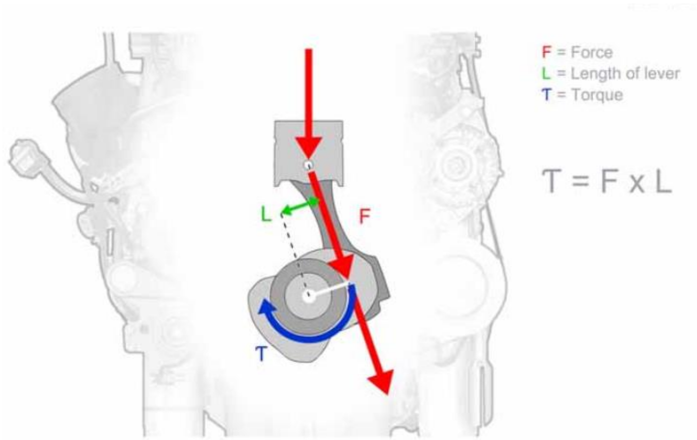


Figure.III.31: Connecting rod-crank system.

Calculation of piston speed

$$V(\theta) = \omega . r \left(\sin\theta + \frac{\mu}{4} \sin 2\theta \right) \qquad [m/s]$$

Piston acceleration

$$J(\theta) = \omega^2 . r(\cos\theta + \mu \cos 2\theta) \qquad [m^2/s]$$

The forces exerted on the piston

The total forces act on the head of the connecting rod.

$F_s = F_g + F_j$

With Fg: the gas force and Fj: the inertia force.

$F_g = P.S$

Or S: the surface of the piston head

$$S = \frac{\pi D^2}{4}$$

Determination of gas pressure force

$V_x = S .c$

where c: is the stroke of the piston.

c = r.(1-cos θ)

- For the admission phase:

$P_g = F_g.S$

- For the compression phase:

$$P_g = S.\left[\frac{P_c(V_c)^{n1}}{\left(V_a - \left(s.r(1-\cos\theta)\right)\right)^{n1}}\right]$$

- For the combustion phase:

$P_g = F_g.S$

- For the relaxation phase:

$$P_g = S.\left[\frac{P_z(V_z)^{n2}}{\left(V_z - \left(s.r(1-\cos\theta)\right)\right)^{n2}}\right]$$

- For the exhaust phase:

$P_g = S.P_r$

- Calculation of the force of inertia Pj:

$P_j = m_b.r.\omega^2.(\cos\theta + \mu.\cos 2\theta)$

Where m_b: the mass of the connecting rod

$m_b = m_{gp} + m_j$

m_{gp}: mass of piston group.

m_j: mass of the connecting rod participated in the movement of the piston [1].

Using the fundamental principle of dynamics, the classical equation obtained for rotational movements gives a relation between the motor torque C_m and the angular acceleration of the crankshaft $\ddot{\theta}$

$$J\ddot{\theta} = C_m - C_r$$

Where C_r: represents the resistive torque of the motor (torque of friction plus torque of load), and J the moment of inertia of the motor shaft. We can also consider a moment of inertia depending on the crankshaft angle and the equation (III.16) then becomes:

$$J(\theta)\ddot{\theta} = C_m - C_r$$

With variable moment of inertia

$$J(\theta) = J_{eq} + M_{eq}r^2 f_1(\theta)^2$$

Or

J_{eq} is the equivalent moment of inertia of the rotating masses.

M_{eq} the equivalent mass of alternating masses.

r is the radius of the crankshaft.

$f_1(\theta)$ a function of the crankshaft angle given by the formula (111.19):

$$f_1(\theta) = \sin(\theta) + \frac{\frac{l}{r}\sin(2\theta)}{2\sqrt{1 - \frac{l^2}{r^2}\sin^2(\theta)}}$$

With l: the length of the connecting rod.

I.15. Simulation of diesel engine in MATLAB Simulink

We simulate the diesel engine in Matlab Simulink, the following figure is modeling diesel engine with blocks:

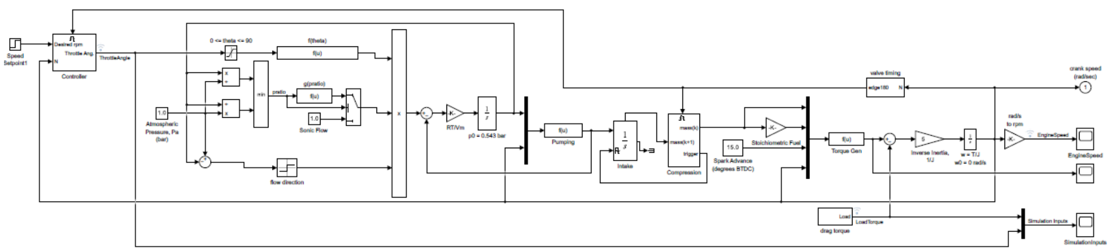


Figure.III.32: Simulation of diesel engine in Matlab Simulink.

The results of diesel engine

We will review the following result:

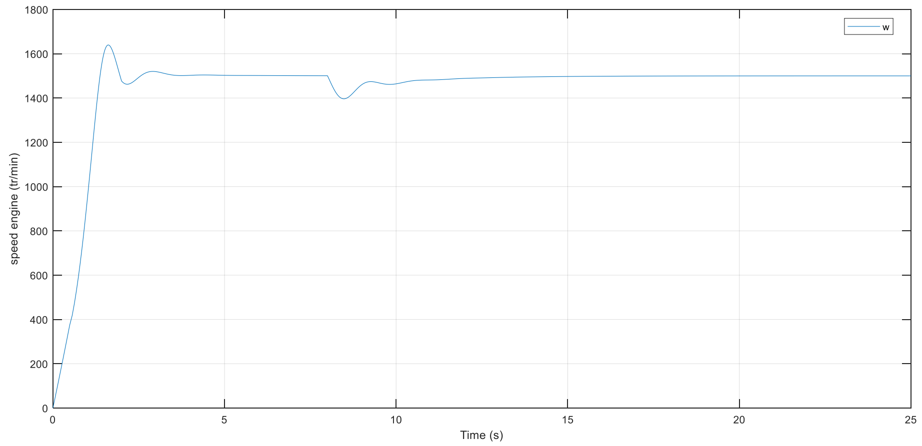


Figure.III.33: The engine speed.

The engine speed increase to 1500 tr/min and fix to that value.

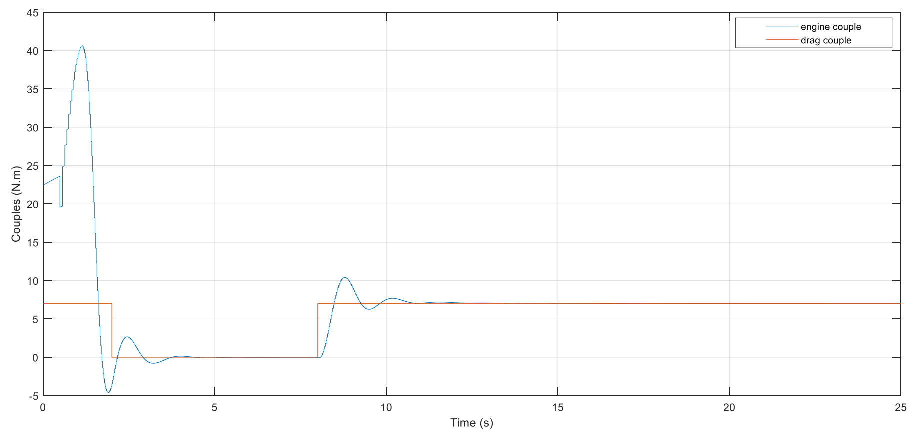


Figure.III.34: The engine torque.

We start the engine with a drag torque 7 N.m, after 2s the charge become zero. At t=8s, we restore the drag torque at 7N.m.

The engine torque is always follow the drag torque which give us the best performance of diesel engine [1].

I.16. Conclusion

In this chapter, we discussed the general operation of a controlled thermal engine, its constituent components, and some of its characteristics.

Atmospheric pollution in densely populated areas has become a truly catastrophic problem for some cities. To significantly reduce vehicle consumption and pollutant emissions, drivers and automakers are working together to develop appropriate methods for driving and controlling the engine's electronic components. Models are used at this stage to better understand the behavior of the engine as well as to synthesize and simulate regulation algorithms.

We have discussed the modeling of commanded ignition engines. The latter focused on dynamic models of the various engine components, namely: combustion, air intake, diesel intake, and crankshaft-crank system dynamics.

The models that are created are then used as a foundation for the synthesis of the motor control laws in the sections that follow [2].

Chapter II

Modeling and simulation of synchronous generator

II.1. Introduction

All of the electrical energy we use is mostly produced by three-phase alternators. The world's largest energy converters are these devices. The alternator transforms mechanical power that it takes in as rotation generates electrical power in the form of alternating current using a straight forward mechanism, producing yields that are near to 100%.

Typically, synchronous machines that are self-excited are employed in generator sets. An armature (the stator) and a movable inductor (the rotor) make up this type of machine [15].

II.2. Description des constituants d'un alternateur

II.2.1 The stator

The stator (figure II.1) is made up of a stack of crown-shaped sheets that are magnetically isolated from one another to reduce eddy currents.

The circuit stator magnet is made up of a group of tightly packed crowns with their insulation. The three-phase winding of the stator is contained in equally spaced notches in the magnetic circuit's interior. To boost the magnetic field produced by the rotor, iron makes up the stator's magnetic circuit. A three-phase stator's winding is made up of three coils that are 120° apart from one another. Each of the terminals on the machine terminal board is where the ends of the winding terminate. They are the winding output and the entry. They are the winding output and the entry. The winding is open, therefore they are not coupled; the coupling must be done by the user [16].

Figure II.1: Stator of a three-phase alternator.

II.2.2 The rotor

Inside the still stator, an electromagnet called the rotor revolves. The impeller door has a winding in the notches placed around its perimeter. We distinguish between three different kinds of rotors: smooth pole, salient pole, and permanent magnet [17].

a. Rotor with smooth poles

The smooth pole rotor is made of a solid cylinder that has been machined with notches (Figure I.11). There are often two or four poles. Due to the steam turbine's rapid rotation, thermal power plants typically use it [17].

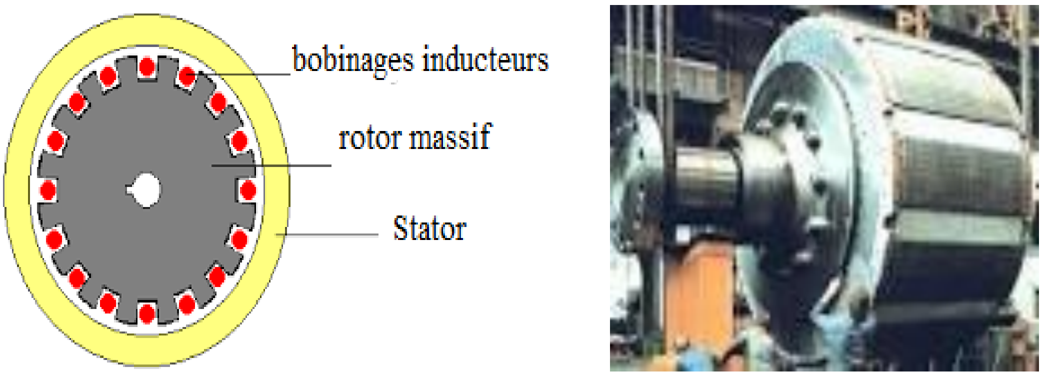


Figure II.1 :Rotor with smooth poles.

b. Salient pole rotor

It is an electromagnet with several poles (more than or equal to 4) that alternately point north and south (figure I.12). Direct current is used to power the wound circuits.

The polar nuclei are encircled by them. Due of their sluggish rotation, hydropower plants typically use it[15].

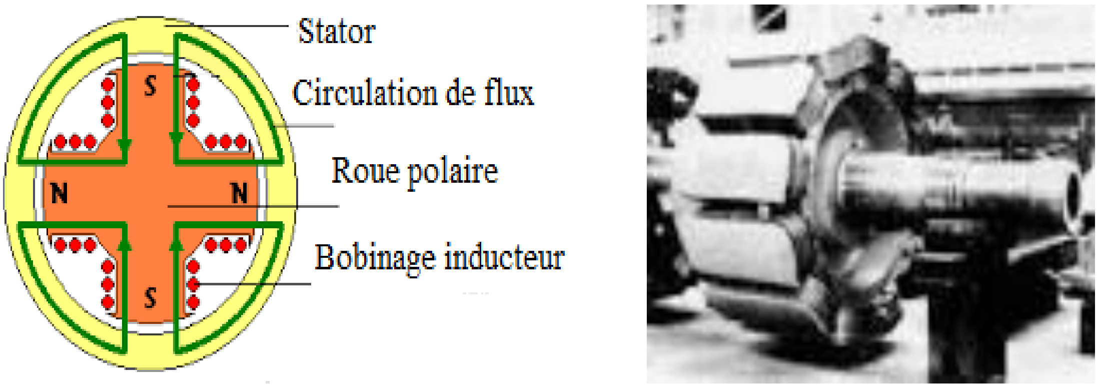


Figure II.2 :salient pole rotor.

c. *Permanent magnet rotor*

Magnets are used in place of the electromagnet (Figure I.13), which has the advantage of getting rid of the ring brush system, rotor losses, and excitation circuit[16].

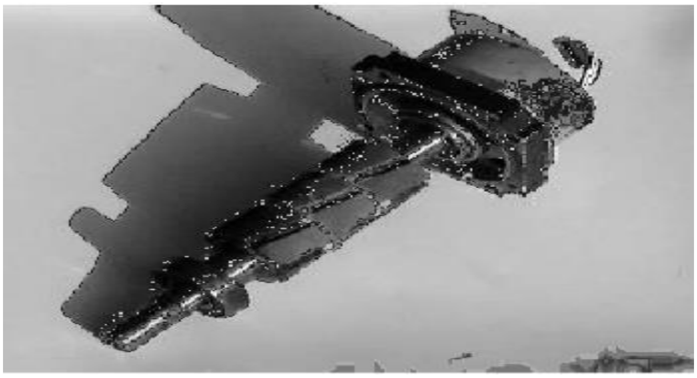


Figure II.3 :Permanent magnet rotor.

II.2.3 Principle of operation of the three-phase alternator

The DC excitation current powers the electromagnet's rotor, which when stimulated while revolving creates a rotating field. An electromotive force is produced in each winding stator as a result of the interaction between this rotating field and the conductors [18].

II.2.4 Alternator voltage regulation

Due to an internal impedance created by the leakage reactance and armature resistance, the alternator's output voltage decreases while it is charging. A voltage regulator is used to keep the output voltage at a reasonable level. An AVR (automatic voltage regulator) is the most used regulator [18].

The AVR is a piece of electronic equipment made up of a number of parts, including diodes, capacitors, resistors, potentiometers, and even microcontrollers. The voltage is supposed to be automatically regulated [15].

II.2.5 Principle of operation of the AVR

The regulator first keeps an eye on the output voltage and manages the input for the voltage alternator exciter. The generator output voltage changes based on the outcome by raising or lowering the voltage of the generator control. Numerous times each second, the regulator determines how much voltage should be given to the exciter in order to stabilize the output voltage at a predetermined instruction level [18].

The circuit in (Figure I.14) serves as an example of the fundamental ideas involved in the stabilization of a generating set's voltage using a self-excited alternator. An alternating voltage is produced in the excitation winding when the rotor is turned by the motor. Bridge rectifier "RB" and filter capacitor "C" transform this alternating current into direct current. The detection circuit toggles transistor "Q" on or off by comparing an output voltage V to a predetermined value. A current runs through the field (rotoric) winding when "Q" is turned on. The freewheeling diode "D" continues to conduct field current even when "Q" is off. When then, the rotor includes a tiny permanent magnet to supply some base current. The output voltage V can be controlled by altering the duty cycle of the transistor "Q"'s operation [15].

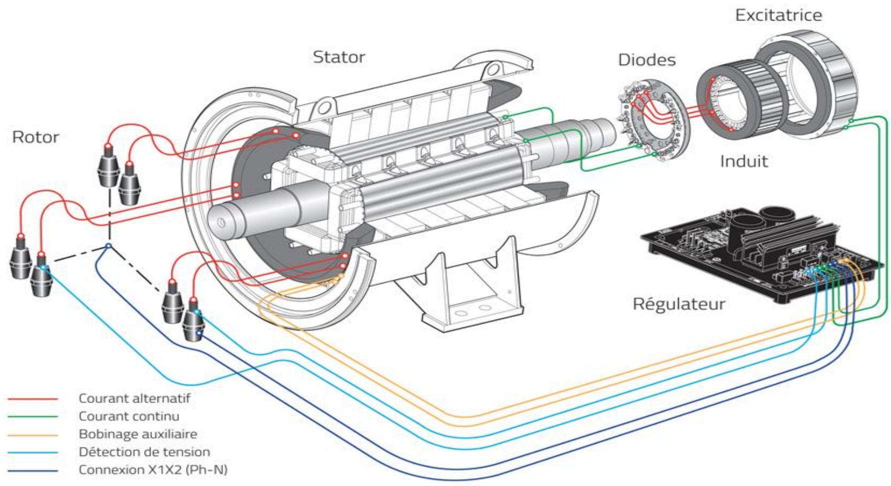


Figure II.4 : Output voltage regulation circuit.

II.3. Presentation of the synchronous generator (alternator)

We first discuss the adoptable simplifying assumptions and sign standards before moving on to modeling the alternator. Its equation will be created by outlining all the connections between the various parameters that control how it functions using the fundamental principles of electrical engineering. This machine is used in accordance with Figure II.5's schematic representation for setting equations [16].

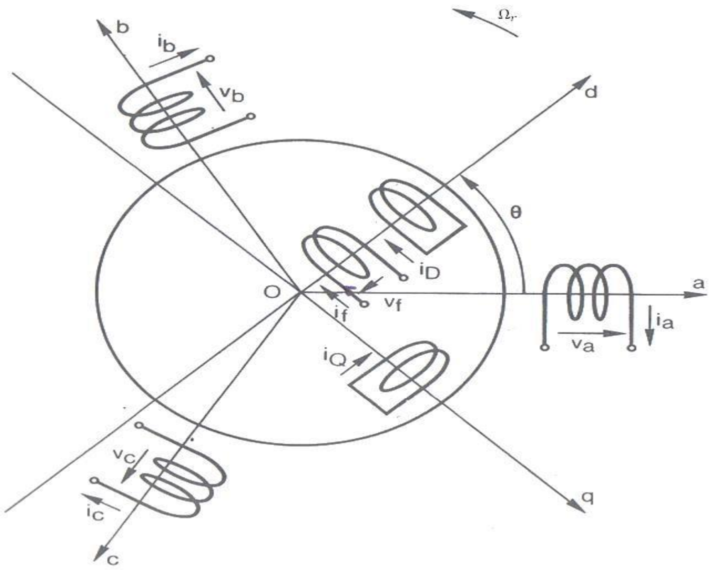


Figure II.5: Schematic representation of the synchronous machine with dampers.

II.4. Electrical and mechanical equations of the synchronous machine with damping windings

II.4.1 Electrical equations of the stator

The Laplace operator "p" will be used in the following to replace the operator d/dt, which denotes a derivation with regard to time.

The machine is controlled by the following equations in the planes (a, b, and c), where Φ_a, Φ_b, Φ_c are the flows crossing each phase at a certain time:

$$\begin{cases} V_a = E_a - R_a i_a = -p\Phi_a - R_a i_a \\ V_b = E_b - R_a i_b = -p\Phi_b - R_a i_b \\ V_c = E_c - R_a i_c = -p\Phi_c - R_a i_c \end{cases} \qquad \textbf{(II-1)}$$

R_a: Resistance of a phase of the stator

i_a, i_b, and i_c are the currents through windings a, b, and c respectively.

V_a, V_b and V_c are the voltages across windings a, b and c respectively.

II.4.2 Park transformation

The equation of the machine according to Park's model is governed by the equations below:

$$\begin{pmatrix} V_d \\ V_q \\ V_0 \end{pmatrix} = \frac{2}{3} * \begin{pmatrix} cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \mathrm{sis}\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{pmatrix} * \begin{pmatrix} V_a \\ V_b \\ V_c \end{pmatrix} \qquad \textbf{(II-2)}$$

$$\begin{pmatrix} i_d \\ i_q \\ i_0 \end{pmatrix} = \frac{2}{3} * \begin{pmatrix} cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \mathrm{sis}\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{pmatrix} * \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} \qquad \textbf{(II-3)}$$

$$\begin{pmatrix}\Phi_d\\ \Phi_q\\ \Phi_0\end{pmatrix}=\frac{2}{3}*\begin{pmatrix}cos\theta & \cos\left(\theta-\frac{2\pi}{3}\right) & \cos\left(\theta+\frac{2\pi}{3}\right)\\ sin\theta & \sin\left(\theta-\frac{2\pi}{3}\right) & \mathrm{sis}\left(\theta+\frac{2\pi}{3}\right)\\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2}\end{pmatrix}*\begin{pmatrix}\Phi_a\\ \Phi_b\\ \Phi_c\end{pmatrix} \quad (\mathbf{II-4})$$

We derive the system of Park equations by applying the transformations specified by systems (II.2), (II.3), and (II.4) to the voltages, currents, and fluxes related to phases a, b, and c.

- In the plane (d,q):

$$\begin{cases}V_d = -p\Phi_d - \Phi_q.p.\theta - R_a i_d\\ V_q = -p\Phi_q + \Phi_d.p.\theta - R_a i_d\\ V_0 = -p\Phi_0 - R_a i_0\end{cases} \quad (\mathbf{II-5})$$

V_d, i_d: Component in the direct rotor axis of the voltage and current per phase after Park transform.

V_q, i_q: Component in quadrature axis of the rotor of voltage and current per phase after Park transformation.

Φ_d: Component of the flux rotating along the direct axis of the rotor.

Φ_q: Component of the flux rotating along the axis in quadrature of the rotor.

θ: Electric angle of the direct axis of the rotor with the axis of the phase a.

If we put: $\frac{d\theta}{dt} = P.\theta = \Omega_r$

Ω_r: rotational speed of the alternator rotor.

We obtain:

$$\begin{cases}V_d = -p\Phi_d - \Phi_q.\Omega r - R_a i_d\\ V_q = -p\Phi_q + \Phi_d.\Omega r - R_a i_d\\ V_0 = -p\Phi_0 - R_a i_0\end{cases} \quad (\mathbf{II-6})$$

After Park transformation, the machine can be represented by Figure II.6.

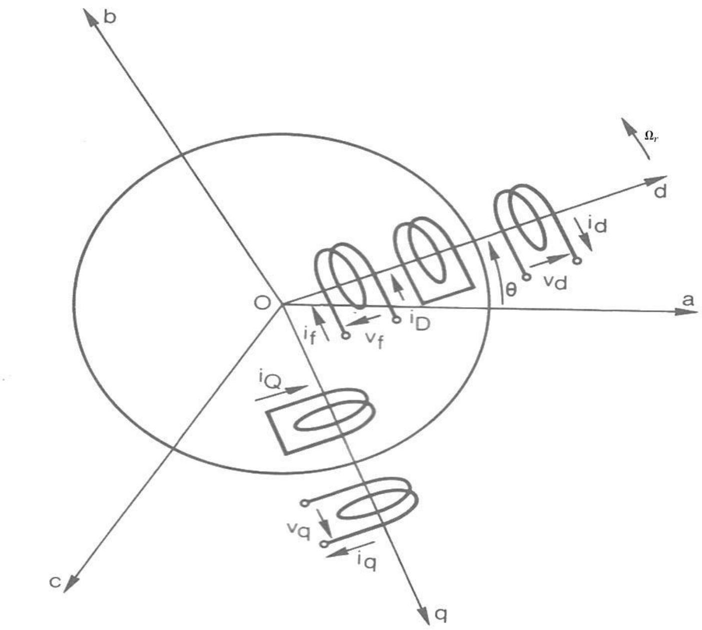


Figure II.6: Schematic representation of the machine Synchronous after Park transformation.

II.4.3 Schematic representation of the machine synchronous after Park transformation.

1. Field windings

The inductor is described by the following equation:

Vf = p. Φf + $Rf\ if$ **(II-7)**

Vf: Voltage across field winding

Φf: Total flux embraced by the field winding

Rf: Field winding resistance

if: Current through field winding

2. Shock absorbers

The voltage being zero at the terminals of the damping circuits, we can write:

$$\begin{cases} 0 = p.\Phi_{kd} + R_{kd}.i_{kd} \\ 0 = p.\Phi_{kq} + R_{kq}.i_{kq} \end{cases} \quad \textbf{(II-8)}$$

II.4.4 Equations of powers, torques and mechanical equations of the machine

In what follows, we give the equations relating to a bipolar machine.

1.Power calculation

The instantaneous power brought into play at the terminals of the machine in the general case, is the sum of the powers of the three phases:

$$P_i = V_a\, i_a + V_b\, i_b + V_c\, i_c \qquad \textbf{(II-9)}$$

This power is positive because the machine operates as a generator, which is according to sign conventions.

We write the voltages (V_a, V_b, V_c) as a function of (V_d, V_q) and the currents (ia , ib , ic) as a function of (I_d , I_q), using the system (II.6) we arrive at the following equation[15]:

$$Pi = \frac{2}{3}(V_d\, i_d + V_q\, i_q) + 2V_0 i_0 \qquad \textbf{(II-10)}$$

2. *Calculation of torques*

By replacing in the expression (II.9) the tensions V_d, V_q by the terms given in the equation system (II.6)

$$P_i = -\frac{2}{3}(id\,.\,p.\Phi d + iq\,.\,p.\Phi q) - \frac{2}{3}(id^2 + iq^2) + \frac{2}{3}(iq\Phi d - id\Phi q)\Omega_r \qquad \textbf{(II-11)}$$

- The first parenthesis is made up of simple phrases with the pattern I. p. Φ. They don't help to produce the power that is electric; instead, they correspond to the power that the machine's changes in electromagnetic energy storage put into action.

- The total of the joule losses of the armature (stator) is shown in the second parenthesis.

- The electromagnetic power P_{ei} is represented by terms of the form IΦ in the third parenthesis.

$$P_{ei} = \frac{2}{3}(i_q\Phi_d - i_d\Phi_q)\Omega_r \qquad \textbf{(II-12)}$$

The factor I.Φ stands for the electromagnetic torque that is a byproduct inside the machine, and P_{ei} is the sole power contained in the formula for P_i that is probable to produce an electrical power.

$$C_{ei} = \frac{2}{3}(iq\Phi d - id\Phi q) \quad \textbf{(II-13)}$$

3.Mechanical equations of the alternator

- The counterclockwise spinning of the machine is caused by the positive direction of the torques, which is chosen to be positive.
- The heat engine's delivered torque Cm must be positively counted [15].

$$J\frac{d^2\theta}{dt^2} = C_m - C_e \quad \textbf{(II-14)}$$

J: Is the moment of inertia of the rotating part.

θ: Is the electrical angle of the rotor, with respect to a fixed axis a.

4. Magnetic Machine Equations

The relationships between currents and fluxes are given in matrix forms below:

- Flow in the direct axis:

$$\begin{pmatrix} \Phi_d \\ \Phi_f \\ \Phi_{kd} \end{pmatrix} = \begin{pmatrix} L_d & M_{af} & M_{kd} \\ \frac{3}{2}M_{af} & L_f & M_{fkd} \\ \frac{3}{2}M_{akd} & Mf_{kd} & L_{kd} \end{pmatrix} * \begin{pmatrix} i_d \\ i_q \\ i_{kd} \end{pmatrix} \quad \textbf{(II-15)}$$

- Flux in the quadrature axis:

$$\begin{pmatrix} \Phi_q \\ \Phi_{kq} \end{pmatrix} = \begin{pmatrix} L_q & M_{akq} \\ \frac{3}{2}M_{akq} & L_{kq} \end{pmatrix} * \begin{pmatrix} i_q \\ i_{kq} \end{pmatrix} \quad \textbf{(II-16)}$$

For the multipolar machine, the equations governing the machine remain unchanged except those of the electromagnetic torque and the equation of motion which become:

$$C_{ei} = \frac{2}{3}p(i_q\Phi_d - i_d\Phi_q) \quad \textbf{(II-17)}$$

$$\frac{J}{p}\frac{d^2\theta}{dt^2} = C_m - C_e \qquad \textbf{(II-18)}$$

p: Number of pole pairs.

II.5. Electrical and mechanical equations of the synchronous machine without damping windings

The form of the electrical and mechanical equations is the same as that of the machine with shock absorbers (II.5, II.6, II.10, II.12, II.13, II.14)

To obtain the magnetic equations, it suffices to take those of the machine with damper and pose windings:

$\Phi_{kd} = \Phi_{kq} = i_{kd} = i_{kq} = M_{akd} = M_{akq} = M_{fkd} = L_{kd} = L_{kq} = 0$

We then obtain the relations between fluxes and currents in the form:

$$\begin{pmatrix}\Phi_d\\ \Phi_f\end{pmatrix} = \begin{pmatrix}L_d & M_{af}\\ \frac{3}{2}M_{af} & L_f\end{pmatrix} * \begin{pmatrix}i_d\\ i_f\end{pmatrix} \qquad \textbf{(II-19)}$$

$\Phi_q = L_q * i_q$

Equations II.8 and II.19 undergo transformations by groupings of terms in order to show measurable quantities that have a physical meaning precise.

$$\begin{cases}\Phi_d = L_d\, i_d + M_{af}\, i_f\\ \Phi_f = \frac{3}{2}M_{af}\, i_d + L_f\, i_f\\ V_f = p\Phi_f + R_a\, i_d\end{cases} \qquad \textbf{(II-20)}$$

By eliminating Φ_f between the last two equations, we obtain:

$$i_f = \frac{V_f - \frac{3}{2}M_{af}.p.I_d}{R_f + L_f.P} \qquad \textbf{(II-21)}$$

By eliminating Φ_f and If between the three equations of the system (II.21) we obtain the expression of Φ_d:

$$\Phi_d = \frac{1+\frac{1}{R_f}.\left(L_f - \frac{3/2\, M_{af}{}^2}{L_d}\right)}{1+\frac{L_f}{R_f}.p}.p.I_d + \frac{M_{af}}{R_f.\left(1+\frac{L_f}{R_f}.p\right)}.V_f \qquad \textbf{(II-22)}$$

In this expression we have:

$L_f - \frac{{}^{3}/_{2} M_{af}{}^{2}}{L_d} = N_f$: to the dimension of a leakage inductor.

$\frac{1}{R_f} \cdot \left(L_f - \frac{{}^{3}/_{2} M_{af}{}^{2}}{L_d} \right) = \frac{N_f}{R_f} = T'_d$: to the dimension of a time constant.

$\frac{L_f}{R_f} = T'_{d0}$: has the dimension of a time constant.

II.6 Simulation of synchronous generator in Matlab Simulink

We simulate the synchronous generator in Matlab Simulink, the following figure is modeling synchronous generator with blocks:

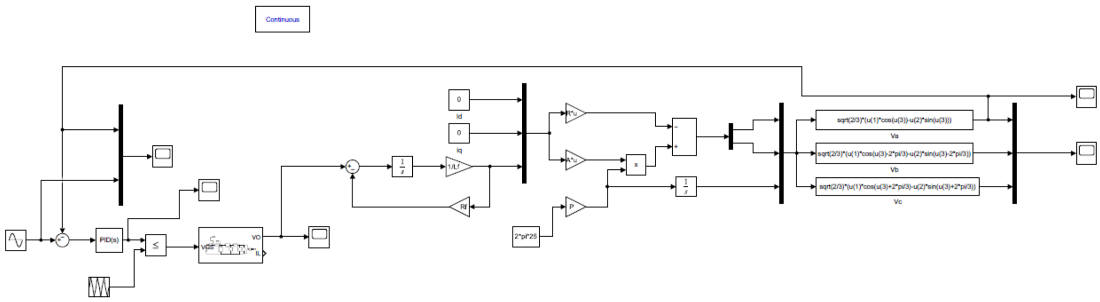


Figure II.7: Simulation of synchronous generator in Matlab Simulink.

The results of synchronous generator

We will review the following result:

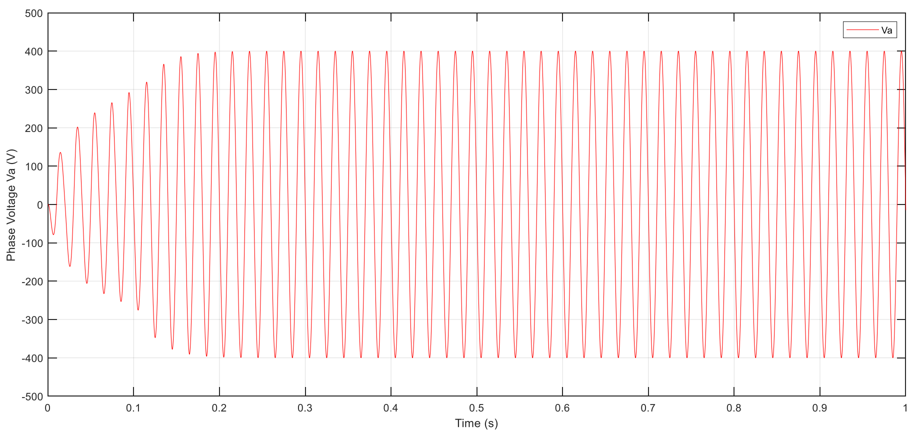


Figure II.8: The voltage in phase A.

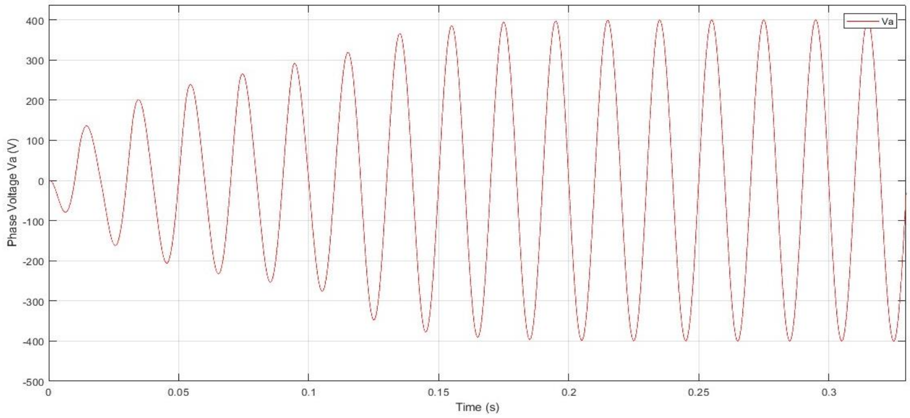


Figure II.9: The voltage in phase A zoom.

The synchronous generator produces an alternative tension of 400 volts and frequency of 50 *Hz* in one phase.

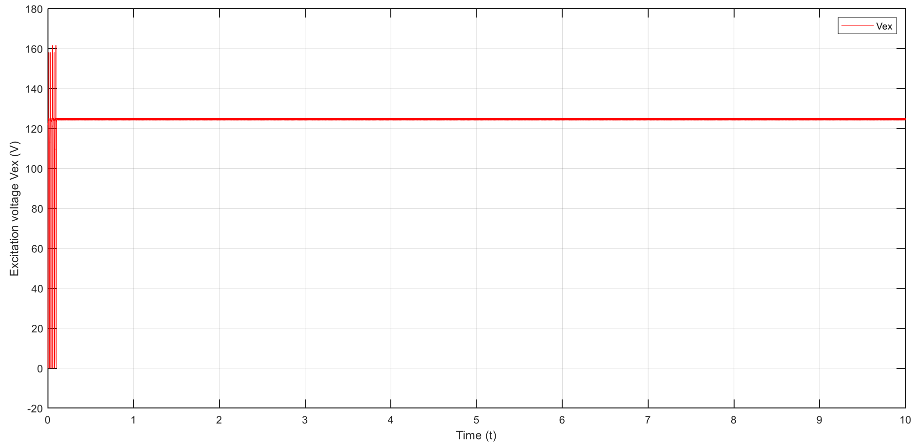


Figure II.10: The excitation voltage.

To produce an alternative voltage from a generator we need an excitation voltage for the rotor, we used a DC-DC converter (chopper) to provide this excitation. So, the chopper produces 125V to excite the generator to produce 400V [18].

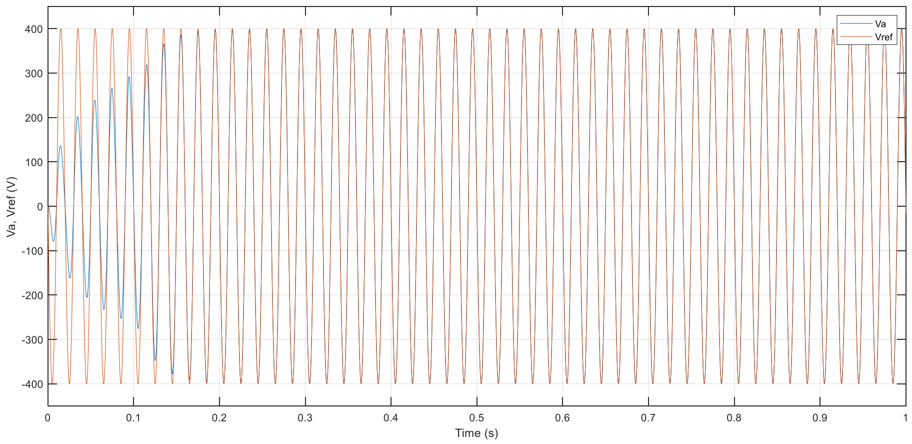


Figure II.11: The measured voltage and reference voltage.

We compare between the measured voltage and the reference voltage, it takes 0.2s for measured voltage to perfectly match with the reference.

7. Conclusion

Generators are instruments that generate electrical energy from mechanical energy, and in this chapter, we presented a mathematical model of synchronous generator and a result of simulation that improve the excitation of a rotor to give the voltage requirement at its terminal with no loading of the generator.

Chapter III

Simulation and results of engine-generator

III.1. Introduction

From the discovery of electromagnetic forces to the invention of electrical energy distribution systems, technologies have grown with the development of increasingly complex machines based on the usage of current electric as a central point. Now that this energy has become one of the most important growth vectors in the most important economic and industrial sectors, it is critical to ensure that its production continues.

Public networks are not always capable of handling the intensity of electricity that many businesses require to run in order to sustain their operations. Generators, which form mobile power, have been designed and polished to overcome all flaws and frequent breakdowns of public networks. Today they become essential and meet several challenges depending on their use [17].

III.2. Definition

An engine-generator is a piece of machinery made up of an electrical generator installed on top of an engine (primary mover). An engine-generator set, sometimes known as a gen-set, is another name for this setup. The engine is frequently taken for granted, and the finished product is just referred to as a generator. An engine-generator may be permanently installed, integrated into a vehicle, or made portable [18].

Engine-generators typically include a fuel supply, a constant engine speed regulator (governor) and a generator voltage regulator, cooling and exhaust systems, and a lubrication system, in addition to the engine and generator. Units larger than about 1 kW often have a battery and electric starter motor; very large units may start with compressed air either to an air driven starter motor or introduced directly to the engine cylinders to initiate engine rotation.

An engine-generator is a device used to produce electricity. It is also said to be an electric current generator.

The engine-generator set provides electrical energy independently.

To do this, the group or alternator needs petrol, natural gas, diesel or works from a hybrid system. This fuel is then used to run the engine. All fuels are able to start a group [18].

A generator can be stationary or mobile. Gen-set power is measured in Watts, kilowatts for active power and Volts for output current voltage. The more powerful a generator, the higher the electricity output.

III.3. Engine-generator components

To know how a generator works, you have to look at the elements that make it up. Some are essential. On the one hand, the heat engine. Then, the alternator or dynamo and finally the control cabinet. We also find:

- a chassis
- an exhaust
- a fuel tank
- an air filter
- a starter for starting
- a pitcher
- a voltmeter
- a battery
- electronic or mechanical control system

The generator must be able to produce electricity continuously, without the need for additional electrical energy [17].

III.4. Engine-generator function

To operate, a generator is first supplied with fuel. This can be gasoline, diesel, biofuel or LPG. The choice is made according to the type of group. This fuel is used directly to operate the heat engine of the unit.

The generator engine produces mechanical energy thanks to the fuel on the one hand, but also thanks to the generator (a dynamo or an alternator). The rotating movement of the dynamo produces a magnetic field which is then transformed into electrical energy to start the generator set [17].

Electricity is produced by the generator:

- A dynamo for direct current

- An alternator that produces alternating current

Figure III.1: An engine-generator.

III.5. The different types of engine-generators

Engine generators come in a variety of power levels. These include small, hand-portable units capable of delivering several hundred watts of electricity, hand-cart mounted units capable of delivering several thousand watts, and stationary or trailer-mounted ones capable of delivering over a million watts. Generators, regardless of size, can run on gasoline, diesel, natural gas, propane, bio-diesel, water, sewage gas, or hydrogen. The majority of the smaller units are designed to run on gasoline (petrol), while the larger ones can run on diesel, natural gas, or propane (liquid or gas). Some engines can run on both diesel and gasoline at the same time (bi-fuel operation) [18].

A-Engines

Many engine-generators use a reciprocating engine and the above-mentioned fuels. This could be a steam engine, which is used in most coal-fired fossil-fuel power plants. Some engine-generators, such as industrial gas turbines used in peaking power plants and micro turbines utilized in some hybrid electric buses, use a turbine as the engine.

The generator voltage (volts), frequency (Hz), and power (watts) ratings are chosen to match the load. Some types of electronic equipment may require an extra power conditioner when using portable engine generators.

Small-scale (less than 1,000 kW) combined heat and power facilities are frequently powered by engine-driven generators that run on natural gas [18].

B-Three phases

The majority of portable units accessible are single-phase generators, whereas the majority of three-phase generators built are massive industrial generators. Portable generators ranging from a few kW to several MW are available in other nations where three-phase power is more widespread in houses [17].

C-Inverter generator

An inverter may be used in small portable generators. Inverter types can generate the necessary power at lower RPMs, decreasing engine noise and increasing fuel efficiency. Because of their low Total Harmonic Distortion, inverter generators are ideal for powering sensitive electronic devices such as computers and lights that employ a ballast.

Because the load on the electric generator causes the engine's speed to decrease, the frequency and voltage of the electrical output suffer. The voltage and frequency of the needed AC output can be kept steady over the power range of the generator by utilizing an electronic inverter [18].

III.6. Engine-generator uses

- **Produce emergency electricity for individuals**

One of the most common uses of the generator set is the backup power generation mode for individuals.

In the home, it can be fixed to back up an electrical installation in the event of a power cut or it can be a backup for a particular use.

For example, when there is a temporary need: to supply light to a house renovation site late at night or for camping during the holidays. These groups, very compact and mobile, are capable of supplying standard current voltages of 230V in single phase and domestic powers of 1 to 10 kW.

The group is a reliable and inexpensive way to obtain electricity at home in the event of a power outage. Well chosen, a generator can power all the appliances in a house. However, it could not replace the public network when it comes to ensuring the production of energy for electric heating [18].

To choose a generator for a house, this is done by taking into account the power of the dwelling and the consumption of the devices to be powered. It must also be rather quiet and autonomous over a long period of time.

The characteristics of the unit's engine are also to be taken into account to determine the usability. For example, the speed of rotation of the group or the duration of autonomy of the tank.

- **Electricity production in the public domain and in companies**

Standby generators can also supply public establishments or businesses in the event of a power failure or breakdown.

Thus, the groups start automatically as soon as a breakdown occurs.

There are many establishments equipped with this type of group: when it comes to endangering human lives (hospitals or EHPAD) or even in strategic places such as banking places, Datacenters, companies with foodstuffs perishables or military premises [17].

Sometimes generators are also the main energy producers. This is the case in places such as football stadiums or the launch site of a shuttle. The group is responsible for the main energy production and in the event of a technical failure, the public network takes over.

- **Choosing the right service provider for the generator set installation**

III.7. Applications of engine-generator

Engine-generators are used to provide electricity in regions where utility (central station) electricity is unavailable or is only required temporarily. On construction sites, small generators are occasionally used to power tools. Trailer-mounted generators power temporary lights, sound amplification systems, amusement rides, and other installations. To determine how many watts are required for a portable generator, use a wattage chart to compute the anticipated power demand for various types of equipment [17].

Diesel generators, whether trailer-mounted or mobile, are also utilized for emergencies or backup when a redundant system is required or there is no generator on-site. A tie-in panel, which has connectors such as camlocks, is typically positioned near the building switchgear to make the connecting faster and safer. A phase rotation indicator (for 3-phase systems) and a circuit breaker may also be included in the tie-in panel. Camlock connections are used with 4/0 type W wire to connect to the generator and are rated for 400 amps up to 480 volt systems. Tie-in panel designs are prevalent in applications ranging from 200 to 3000 amps.

Standby generators are permanently installed and utilized to provide immediate power to important loads during temporary outages in the utility power supply. Standby power generators are installed in hospitals, communications service sites, computer processing centers, sewage pumping stations, and a variety of other critical infrastructure. Some standby power generators can detect a loss of grid power, start the motor, run on natural gas line fuel, identify when grid power is restored, and then turn itself off—all without human intervention [18].

Generators operated by individuals are especially popular in locations where grid electricity is unreliable or absent. Trailer-mounted generators can be towed to disaster zones where power is temporarily out.

III.8. Safety about engine-generator

Every year, deaths from carbon monoxide poisoning are caused by improperly used portable generators. A 5.5 kW portable generator produces the same amount of carbon monoxide as six cars, which can quickly accumulate to lethal amounts if the generator is used indoors. Carbon monoxide poisoning can also occur when portable generators are used in garages, near open windows, or near air conditioning vents.

Furthermore, when using a portable engine generator, it is critical to avoid backfeeding, which can endanger utility personnel or people in nearby buildings. Before starting a diesel or gasoline-powered generator, make sure the primary breaker is in the "off" position to prevent the electric current from reversing [18].

Factory-built positive pressure chimneys (approved to UL 103 test standard) or regular utility schedule 40 black iron pipe can be used to exhaust highly hot flue gases from generators. Insulation is recommended to lower pipe skin temperature and excessive heat input into the mechanical room. Excessive pressure relief valves are also available to alleviate pressure from probable backfires while maintaining the integrity of the exhaust pipe [16].

III.9. Simulation of engine-generator in Matlab Simulink

We simulate the engine-generator in Matlab Simulink, the following figure is modeling engine-generator with blocks:

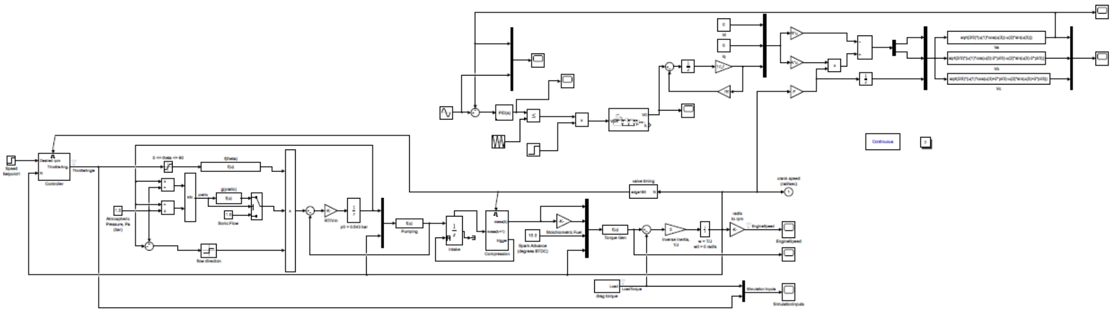


Figure III.2: Simulation of engine-generator in Matlab Simulink.

The results of the engine-generator

At first, the engine speed does not stable until a time of 8.5s. so we'll not lunch the excitation until that time in order to ensure good results.

We will review the following result:

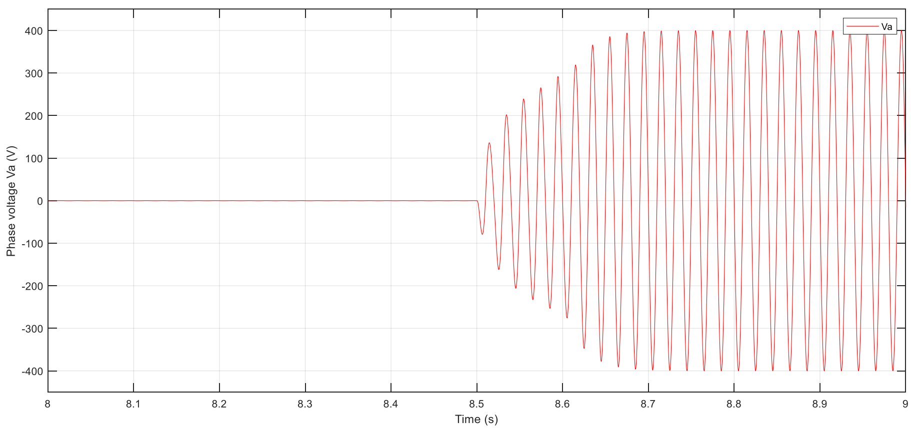


Figure III.3: The voltage in phase A.

After 8.5s, we lunch the excitation to the rotor and the voltage increase to 400V.

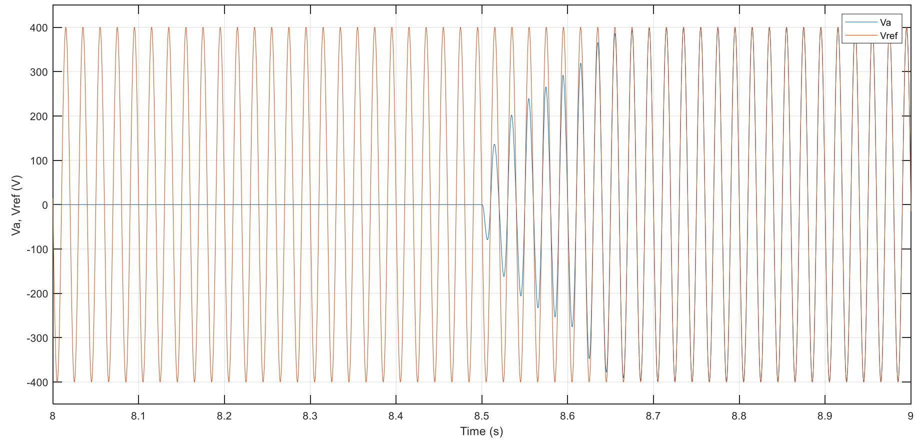


Figure III.4: The excitation voltage

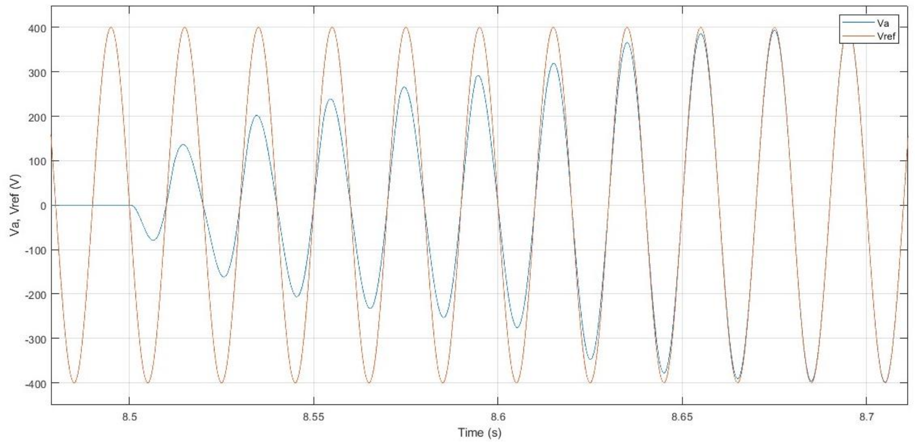


Figure III.5: The excitation voltage ZOOM

Same in this figure, after 8.5s the measured tension follows the reference.

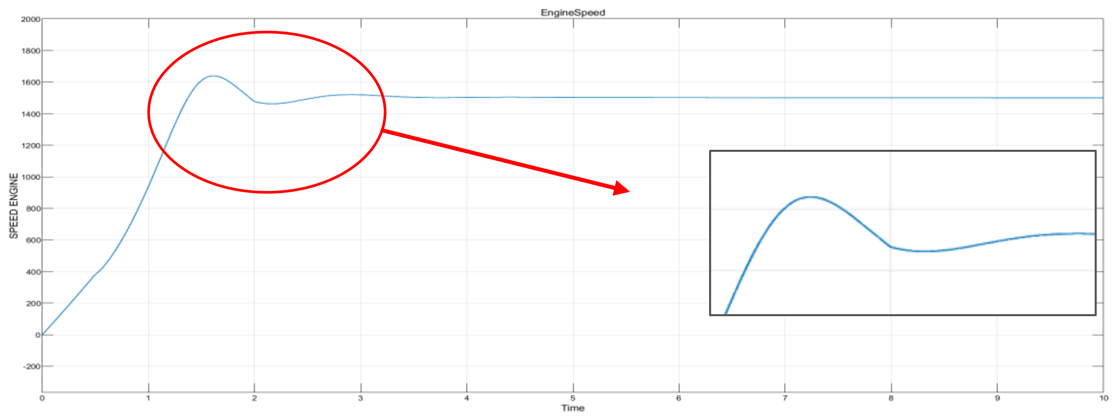


Figure III .6: The engine-generator speed.

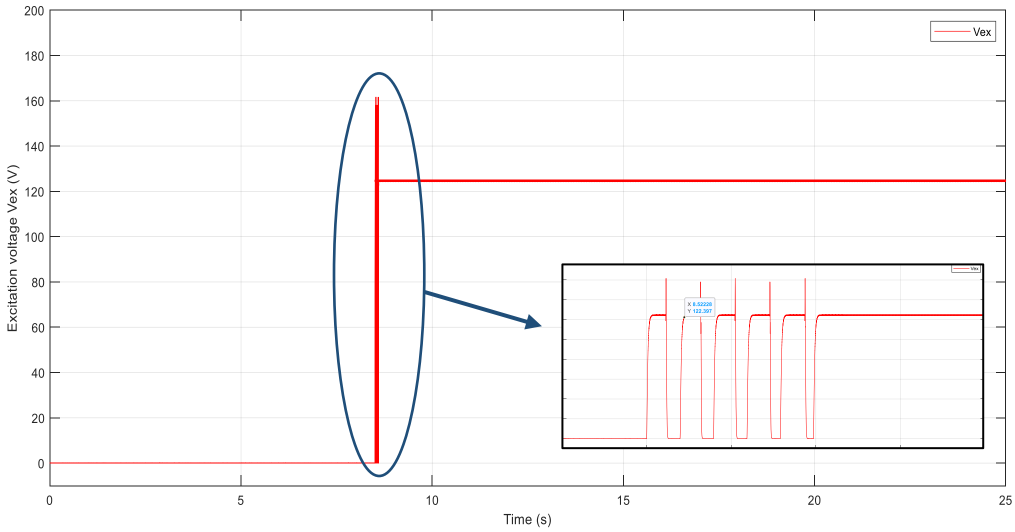


Figure III .7: The measured voltage and reference voltage of the cuk.

III.10. Conclusion

Generating sets, which consist of an engine and an alternator, are frequently used in industrial and commercial buildings, either as the primary source of electrical energy or to provide loads.

In the event that the public distribution network fails, this is critical. In its emergency or production applications, the generator provides benefits such as:

- A wide range of power.

- Quickness of implementation.

- Capacity to work for long periods of time.

These advantages position it well ahead of all other sources of substitution. As a result, it is fair to assert that the generating set is always a product of the future, especially because the performance of the diesel engine in terms of efficiency, dependability, and pollution is always improving.

General conclusion

Diesel engine-driven generator provide essential reliability in an extensive range of electrical power generation applications worldwide, in term of increase the number of using it in the near future. The installation of diesel generators on many ships, offshore where no mains connection is available or at hospitals, data centres, laboratories, factories, etc, provide a critical backup supply in the case of mains failure

The operational requirements for this engine depend to a large extent on the type of application in which they are installed. Ensuring sufficient power quality, that is, maintaining satisfactory frequency and voltage levels, is the fundamental objective in applications where one or multiple gensets provide the electrical supply.

Our study provides a functional description of a diesel driven generator set, which was conducted to present the simulation model based on relevant physical principles of a diesel engine driving a synchronous generator suitable for applying supervisory control with PID regulator.

Additionally, it must to controlled injection heat engine, the engine cycle of the 04 strokes of operation according to the crankshaft angle, and the energy balancing according to the Clapeyron cycle.

Furthermore, A presentation of synchronous generators as frequency, by no load of terminal voltage, excitation voltage, based on the fundamental equations, which they provided by the MATLAB Simulink software

Finally, Due to their high reliability and low cost, diesel-driven generator sets continue to be the preferred choice whenever the power infrastructure is weak or requires backup

Bibliographic references

[1] Djamel KHIAR, « Modélisation et Commande d'un Moteur Thermique à Allumage Commandé » thèse doctorat, Spécialité Automatique, 04 mai 2007.

[2]http://dspace.univmsila.dz:8080/xmlui/bitstream/handle/123456789/8767/2008.23.pdf?sequence=1&isAllowed=y

[3] Frédéric Grousson, « Définition et mise en oeuvre de lois de commande à modèle interne pour un moteur thermique à injection directe d'essence **»,** thèse doctorat, Spécialité Automatique, 3 Octobre 2000.

[4] Guillaume Colin « Contrôle des systèmes rapides non linéaires: Application au moteur à allumage commandé turbocompressé à distribution variable » Thèse doctorat, Spécialité Energétique, 12/10/2006.

[5] John B.-Heywood, Professor of Mechanical Engineering, « Internai combustion engine fundamentals » Editions: McGraw HILL, Automotive Technology series 1988.

[6] Anna Stefanopoulou, « Modeling and Control of Advanced Technology Engines», Thèse doctorat, 1996

[7] A/sayed Med & Touatit Salah, « Elaboration d'un programme de calcul des processus thermodynamique, cinématique et dynamique réels des moteur à combustion interne », PFE, ingénieur, 2003.

[8] Alain Dauron, « modélisation et commande d'un moteur à combustion interne application à la régulation de richesse », thèse doctorat, 20 juin 1991.

[9] Olivier GRONDIN « Modélisation du moteur à allumage par compression dans la perspective du contrôle et du diagnostique » , Thèse PhD; Spécialité: Énergétique ,13 décembre 2004

[10] Per Andersson, «modeling and architecture examples of model based engine control ».

[11] Willard W. Pulkrabek "Engineering Fundamentals of the Internal Combustion Engine" Editions Prentice Hall, 1998

[12] Ping Zeng, Dennis N.Assanis "The developpement of computer-based teaching tool for interna! combustion engine course " Proceedings of IMECE 2004- Nov 13-19-2004 Anaheim California USA.

[13]Mr. NAAMI Hemza, Mr. FERHAT Said « Modelisation et commande d'un moteur a allumage commande pour vehicule hybride » dipôlme d'ingenieur d'état en génie électrotechnique, Université Msila 2007/2008.

[14] P. Barret, "Régimes transitoires des machines électriques tournantes", Edition EYROLLES, 1987.

[15] J. Delmas, "Catalogue groupe électrogène CAT"

[16] http://portable.generatorguide.net/avr.html, consulté le 10/07/2016

[17] Chafa Aliane Aziz Zerioul, « Etude d'un groupe électrogène par simulation numérique », Mémoire de Fin d'Etudes de MASTER PROFESSIONNEL, universite mouloud mammeri de tizi-ouzou *16 /07/2016*

[18]https://en.wikipedia.org/wiki/Engine-generator

Annex

Motor parameters

*	Type of cycle	Four times
n_{cyl}	Number of cylinder	6 (online)
*	Number of valves per cylinder	2
*	Injection order	1-3-4-2
D	Bore diameter	0.1(m)
C	Course	0.13(m)
r	Crankshaft radius	0.065(m)
l_b	Connecting rod length	0.18(m)
m_{gp}	Piston group mass	0.7(m)
S	Cylinder section	$7.85*10^{-3}(m^3)$
μ	Crankshaft ratio	0.36
τ	Compression ratio	8
V_d	Cylinder volume	0.599 l
J	Motor moment of inertia	0.14
C_m	Max torque	88 N.m

PID Controller of Engine

KP	0.089
KI	0.054
KD	0,00231

Generator parameters

V_f	220
R_a	0.48
J	0.263
F	0
P	2
R_f	10
M_f	0.05
L_d,L_q	0.0231
L_f	0.0924
R_a	$\begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \end{bmatrix}$
L	$\begin{bmatrix} -L_d & 0 & M_f \\ 0 & -L_q & 0 \end{bmatrix}$
A	$\begin{bmatrix} 0 & -L_q & 0 \\ -L_d & 0 & M_f \end{bmatrix}$
R_f	$\begin{bmatrix} 0 & 0 & R_f \end{bmatrix}$
L_f	$\begin{bmatrix} -M_f & 0 & L_f \end{bmatrix}$
KP	14,61724
KI	0,00459
KD	0,00087