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Performance of Electronic Governor and Embedded Systems for Locomotive Operation

اداء الحاكمة الالكترونية والانظمة المدمجة في تشغيل القاطرة

A Dissertation Submitted for Partial Fulfillment for the Requirement of M.Sc. Degree in Mechatronics Engineering

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قال تعالى

((قالو سبحنك لا علم لنا إلا ما علمتنا إنك أنت العليم الحكيم))

صدق الله العظيم

سورة البقرة الاية 32

DEDICATION

My humble effort I dedicate to my loving father, mother and sisters.

Whose affection, love and encouragement make me able to get such success and honor, along with all hard working and respected teachers.

ACKNOWLEDGEMENT

I would like to express my sincerest thanks to my supervisor Ust. Abdalla Salih Ali for his support, guidance and advice in completing this thesis.

I would like to extend my thanks to my workmate in Railway Corporation for their excellent assistance, and for providing me with valuable information.

I would like to express my gratitude to all people whom supported me in preparing this thesis.

ABSTRACT

The performance of diesel engines is heavily influenced by their injection system design. In fact, the most notable advances achieved in diesel engines resulted directly from superior fuel injection system designs. While the main purpose of the system is to deliver fuel to the cylinders of a diesel engine, it is how that fuel is delivered that makes the difference in engine performance, emissions, and noise characteristics.

The objective of the present work is to evaluate performance of a system that contains electronic control using embedded system and engine with Electronic Control Module (ECM), comparing it with other system operated with mechanical governor.

The content and function of each system have been discussed. The efficiency of the electronically-controlled engine has been verified using MATLAB software. According to simulation results, electronically-controlled engine give the better performance and less fuel consumption compared to mechanical governors based-system.

مستخلص

أداء ماكنة الديزل يتأثر بشكل كبير بتصميم نظام الحقن. في الحقيقة معظم المميزات الملاحظة تحقق في ماكنات الديزل نتجت مباشرة من مراقبة تصميم حقن الوقود. والغرض الاساسي من النظام هو نقل الوقود الى اسطوانات ماكنة الديزل , كيفية نقل الوقود تشكل فارق في اداء الماكنة والانبعاث والضجة. الغرض من هذا البحث هو تقييم اداء نظام يحتوي على نظام الكتروني يستخدم الانظمة المدمجة وماكنة تحتوي على وحدة تحكم الكترونية مقارنة مع اخر يعمل مع حاكمة ميكانيكية.

تمت مناقشة محتويات وعمل كل نظام .كفاءة نظام التحكم الالكتروني للماكنة تم التحقق منه باستخدام برنامج ماتلاب. استنادا على نتائج المحاكاة نجد أن نظام التحكم الالكتروني للماكنة يعطي اداء افضل واستهلاك اقل للوقود مقارنة بالنظام المعتمد على الحاكمة الميكانيكية.

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LIST OF SYMBOLES

Symbol	Description
R□	Armature resistance, Ω
V	Supply voltage, V
I□	Motor current, A
Eb	Back emf, V

LIST OF ABBREVIATIONS

Abbreviation	**Description**
ECM	Electronic Control Module
ECU	Electronic Control Unit
NOx	Nitrogen Oxides
PID	Proportional Integral Derivative
TTL	Transistor Transistor Logic
DC	Direct Current
CPU	Central Processing Unit
RAM	Random Access Memory
ROM	Read Only Memory
EPROM	Erasable Programmable Read Only Memory
PROM	Programmable Read Only Memory
AC	Alternating Current
EUIs	Electronic Unit Injectors
SCAC	Separate Circuit After Cooling
JWAC	Jacket Water After Cooling
ET	Electronic Technician
SCD	Signal Converting Device
HMI	Human Machine Interface
GE	General Electric
PLC	Programmable Logic Controller

CHAPTER ONE

INTRODUCTION

1.1 General Concepts

The modern electronically-controlled engines which achieve fuel injection, exhaust valve actuating and starting air systems through ECM. Lower specific fuel oil consumption, especially in partial loads and less maintenance cost can be obtained. Easy control stable low load operation with good engine performance. Easy change of operating modes and fine-tuning of operating conditions are possible during operation. Excellent engine condition (higher reliability), appropriate fuel injection pressure and optimum injection timing, most favorable for the combustion condition at any load. An engine diagnosis system, DOCTOR-DIESEL, assures stable operation and management of the spare parts and maintenance interval. The embedded systems contain of microprocessors, memory units, analog to digital converters and output interface units[1].

1.2 Problem Statement

The mechanical governors and distributor diesel fuel injection pumps could no longer deal with the ever increasing demands for efficiency, emission control, power and fuel consumption so will use the ECM.

The ECM system is make meter the appropriate quantity of fuel, as demanded by the speed off, and the load on, the engine at the given time, economic and ecological by utilizing the advancement in this technology.

1.3 Objective

1. To analyze the performance of the Electronic governor and embedded systems (case study 1) used in locomotive operation.

2. To analyze the performance of the Mechanical governors (case study 2) used in locomotive operation.

3. To compare between the two systems.

1.4 Methodology

This system provides greater ability for precise measuring, data processing, operating environment flexibility and analysis to ensure efficient diesel engine operation. It contains embedded systems, position sensors, temperature sensors, actuators or solenoids, pressure sensors. The embedded system composed of microprocessors, memory units, analog to digital converters and output interface units, the main actions of this system are registering operation conditioning and deciding the change.

Microprocessors which process information from various sensors in accordance with programmed software and outputs required electrical signals into actuators and solenoids.

The control system measure the temperature of engine oil, water, and ambient temperature, and measure the atmospheric pressure, filters pressure, inlet outlet also measure position of gear engine and then send signal to the engine motor. This research will compare the performance of ECM with mechanical governor system.

1.5 Thesis Layout

This thesis consists of five chapters. The contents of each chapter are explained as follows:

Chapter one presents general concepts, problem statement, objectives, methodology and layout.

Chapter two consists of literature review. Various Direct Current (DC) motors types are discussed. Finally, the background of the microcontroller, alternator and MATLAB are presented.

In chapter three the two systems has been study in detail.

In chapter four the operations of two systems has been simulated using MATLAB software. The comparison among these two systems also presented in this chapter.

Chapter five consists of conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Previous Studies

The engine speed controller used in heavy duty/off road conventional diesel engine by the adaption of mechanical/electronic governor. In order to control engine speed, the governor controls the amount of fuel using fuel rack. In mechanical type the flyweights present in centrifugal governor are used to control the fuel rack which in turn controls the plunger present in fuel injection pump to control the fuel input to the engine according to the speed of the engine or as per the engine demand. In electronic governor the fuel rack is connected to throttle actuator lever and driven from Electronic Control Unit (ECU) in electronic governor. We have retrofit mechanical governor to electronic governor to obtain smoother and better performance of engine. Worldwide electronic explosion is so that even for a small purpose we are addicted to use electronic instruments, equipments or devices. Present day electronics has grown so much that it is overtaking all the conventional methods and is setting up its own platform. By retrofitting old device to electronically control devices. These things are happing due to its reliability, flexibility and capability of digital electronics [2].

The engine speed controller of a conventional diesel engine is called a Governor. In order to control engine speed, the governor controls the amount of fuel using fuel rack. The fuel rack is connected to throttle actuator lever and driven from microcontroller. The actuator motion is controlled to achieve set-point RPM so required pulse width modulation duty cycle to drive actuator is calculated from digital PID algorithm. PIC 16F877A microcontroller based hardware is developed for the implementation of the controller. The system broadly involves interfacing hardware and the software for PID algorithm. A continuous PID controller is governed by an equation which describes the dynamic time varying behavior of the input or the error signal. This is digitized using numerical approximations and is programmed in the microcontroller. This system is a closed loop control system with feedback signal generated by a digital magnetic pickup, which gives a pulse output which is TTL compatible. The PID algorithm along with the hardware achieves the speed control of the diesel engine. The hardware and software are validated in real time by considering different speed settings [3].

For one hundred years since the birth of the diesel engine, diesel engines have been developed to improve three major factors, i.e. thermal efficiency, power rate, and reliability. At present, diesel engines are facing new important issue, environmental friendliness, and most technological efforts have been concentrated on this issue. Mitsubishi Heavy Industries, Ltd. (MHI) had completed the development of the electronically controlled engine, the UEC Eco-Engine, with its own technology for more environmental friendliness with much enthusiasm, in addition to high performance and reliability in any operating condition, which are the traditional main features of the UEC engine. The Eco-Engine is driving fuel injection pump, exhaust valve, starting air valve, and cylinder lubricator with electronic control system. The UEC Eco-Engine can bring less operating cost and stable operation in addition to reduction of Nitrogen Oxides (NOx) emission and smokeless operation. It is already completed the development of the UEC33LSII-Eco, the UEC50LSII-Eco, and the UEC60LSII-Eco and extend to larger bore size engines.

The fundamental mechanism of the electronically controlled engine has been verified on single-cylinder research engines (NC33 and NC45) at MHI Nagasaki Research and Development Center since 1988. The prototype system has been under commercial running on the 7UEC33LSII-Eco as a stationary diesel generating set at MHI Kobe Shipyard and Machinery Works over two and a half years with very good service experience.

It convinced that the UEC Eco-Engine has much flexibility for environmental friendliness based on actual running results. In this paper, it introduces the system construction, the development concepts, and major test results on research engines and the first full-scale Eco-Engine [4].

The paper presents a review of electronic governors as developed and used by industry. The current interest in the conservation of energy has led many users of prime-mover equipment to develop better control technology for their equipment. This paper deals with the development of the electronic governor and discusses the effects of these control devices on the operation of the industrial equipment.

The basic operation of governors is discussed with the fundamental operational behavior of governors being presented including a brief review of the applicable control theory parameters. Also the industrial development and usage of the electronic governor is described. Several areas are pointed out by industrial users for development of electronic governors. The operational characteristics of several electronic governors are given along with the advantages and disadvantages of using these governors [5].

2.2 DC Motors

Direct-current motors are extensively used in variable-speed drives and position-control systems where good dynamic response and steady-state performance are required. Examples are in robotic drives, printers, machine tools, process rolling mills, paper and textile industries, and many others. Control of a DC motor, especially of the separately excited type, is very straightforward, mainly because of the incorporation of the commutator within the motor. The commutator brush allows the motor-developed torque to be proportional to the armature current if the field current is held constant. Classical control theories are then easily applied to the design of the torque and other control loops of a drive system.

The mechanical commutator limits the maximum applicable voltage to about 1500V and the maximum power capacity to a few hundred kilowatts. Series or parallel combinations of more than one motor are used when DC motors are applied in applications that handle larger loads. The maximum armature current and its rate of change are also limited by the commutator [6]. DC motors are widely used in industrial applications, robot manipulators and home appliances, because of their high reliability, flexibility and low cost, where speed control of motor are required. Therefore, more advanced control techniques need to be used which will minimize the noise effects, there are three basic approaches to intelligent control: knowledge based expert systems, fuzzy logic, and neural networks.

2.2.1 Advantages and disadvantages of DC motor

The advantages and disadvantages of DC motor are listed in table 2.1

Table 2.1 Advantages and disadvantages of DC motor

Advantages	Disadvantages
Ease of control	High maintenance
Deliver high starting torque	Large and expensive (compared to induction motor)
Near-linear performance	Not suitable for high-speed operation due to commutator and brushes

2.2.2 Types of DC motor

- Separately exited DC motor.
- Self-exited DC motor these are further classified into several types:
  - DC shunt motor
  - DC series motor
  - Brushless DC motor
  - Compound motors

2.2.3 Separately excited DC motor

In separately excited DC motors, the field winding is supplied from a separate power source. That means the field winding is electrically separated from the armature circuit. Separately excited DC generators are not commonly used because they are relatively expensive due to the requirement of an additional power source or circuitry. They are used in laboratories for research work, for accurate speed control of DC motors with Ward-Leonard system and in few other applications where self-excited DC generators are unsatisfactory. In this type, the stator field flux may also be provided with the help of permanent magnets (such as in the case of a permanent magnet DC motors) [7]. This type of motors is used in trains and for automatic traction purposes. Figure 2.1 shows the equivalent circuit of separately excited DC motor.

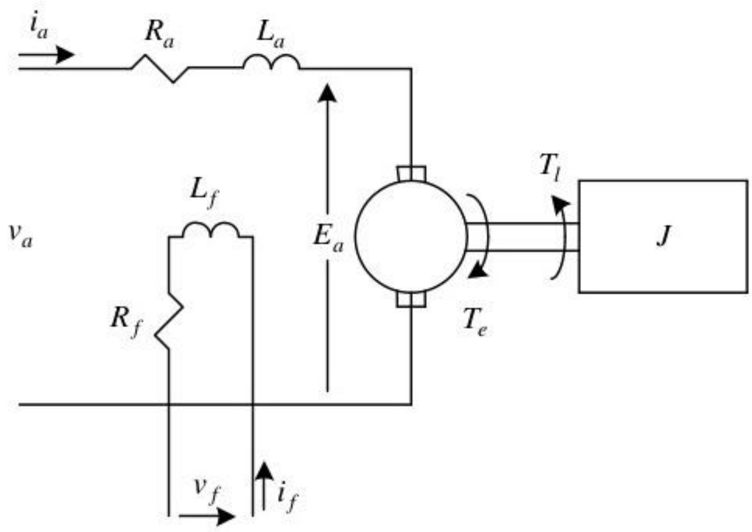


Figure 2.1: Equivalent circuit of separately excited DC motor

- Operation of separately excited DC motor:

i) When a separately excited DC motor is excited by a field current I_f and an armature current I_a of flows in the circuit, the motor develops a back emf and a torque to balance the load torque at a particular speed.

ii) The I_f is independent of the I_a. Each winding are supplied separately. Any change in the armature current has no effect on the field current.

iii) The I_f is normally much less than the I_a [8].

The back emf is given be the relationship:

$$Eb=V-I\text{Ra} \quad (2.1)$$

Where:

$\boldsymbol{Eb}$= Back emf.

$\boldsymbol{V}$= Supply voltage.

$\boldsymbol{Ra}$ = Armature resistance.

$\boldsymbol{I}$=$\boldsymbol{I_a}$ = Armature current.

2.3 Microcontroller

Microcontroller is an integrated chip that is often part of an embedded system. It is included a Central Processing Unit (CPU), Random Access Memory (RAM), Read Only Memory (ROM), input port, output port and some of special function like timer. But, usually microcontrollers including Erasable Programmable Read Only Memory (EPROM) and Programmable Read Only Memory (PROM). These types of memories are permanently integrated into a chip and connected internally by an internal bus. It is designed to execute only a single specific task to control a single system. They are much smaller and simplified so that it can include all the function required on a single chip. Microcontrollers can be categorized as 8-bit, 16-bit and 32-bit, which is that, is the most used [9].

2.4 Alternator

An alternator is an electrical generator that converts mechanical energy to electrical energy in the form of alternating current. For reasons of cost and simplicity, most alternators use a rotating magnetic field with a stationary armature. Occasionally, a linear alternator or a rotating armature with a stationary magnetic field is used. In principle, any Alternating Current (AC) electrical generator can be called an alternator, but usually the term refers to small rotating machines driven by automotive and other internal combustion engines. An alternator that uses a permanent magnet for its magnetic field is called a magneto. Alternators in power stations driven by steam turbines are called turbo-alternators. Large 50 or 60Hz three phase alternators in power plants generate most of the world's electric power, which is distributed by electric power grids. Figure 2.2 shows equivalent circuit of an alternator[10].

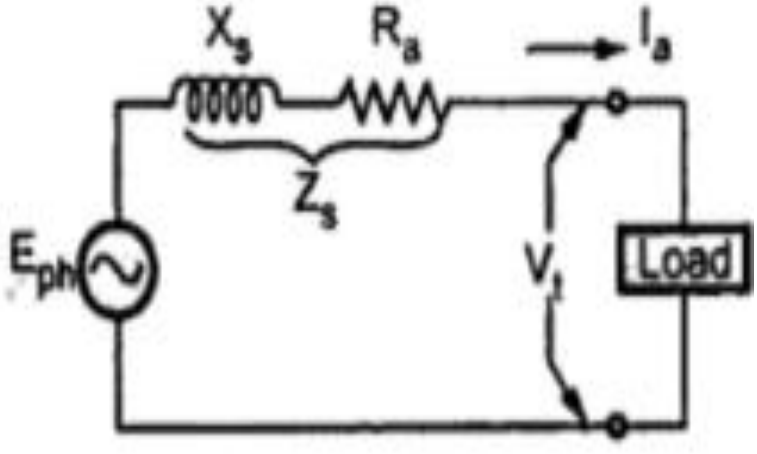


Figure 2.2: Equivalent circuit of an alternator

- Principle of operation an alternator:

A conductor moving relative to a magnetic field develops an electromotive force (emf). This emf reverses its polarity when it moves under magnetic poles of opposite polarity. Typically, a rotating magnet, called the rotor turns within a stationary set of conductors wound in coils on an iron core, called the stator. The field cuts across the conductors, generating an induced emf , as the mechanical input causes the rotor to turn. The rotating magnetic field induces an AC voltage in the stator windings. Since the currents in the stator windings vary in step with the position of the rotor, an alternator is a synchronous generator.

The rotor magnetic field may be produced by permanent magnets, or by a field coil electromagnet. Automotive alternators use a rotor winding which allows control of the alternator's generated voltage by varying the current in the rotor field winding. Permanent magnet machines avoid the loss due to magnetizing current in the rotor, but are restricted in size, due to the cost of the magnet material. Since the permanent magnet field is constant, the terminal voltage varies directly with the speed of the generator. Brushless AC generators are usually larger than those used in automotive applications.

An automatic voltage control device controls the field current to keep output voltage constant. If the output voltage from the stationary armature coils drops due to an increase in demand, more current is fed into the rotating field coils through the Voltage Regulator (VR). This increases the magnetic field around the field coils which induces a greater voltage in the armature coils. Thus, the output voltage is brought back up to its original value [10].

2.5 MATLAB

MATRIX LABOROTARY (MATLAB) is an interactive software system for numerical computations and graphics. As the name suggests, MATLAB is especially designed for matrix computations: solving systems of linear equations, computing eigenvalues and eigenvectors, factoring matrices, and so forth. In addition, it has a variety of graphical capabilities, and can be extended through programs written in its own programming language [11].

CHAPTER THERE

SYSTEM IMPLEMENTATION

3.1 Introduction

In this research there are two cases sinario the first one is an electronic control system refers to here as (case study 1) and the other one is traditional mechanical governor refers to here as (case study 2).

3.2 Case Study 1

The internal combustion locomotive is designed as AC-DC electrically driven locomotive, with the diesel engine manufactured by caterpillar type 3500B (this engine is the prime-mover in the locomotive under study) driving a three-phase synchronous generator (referred to as main generator). The three-phase alternating current generated by the main generator, after three-phase bridge rectification made by silicon rectifying cabinet, is transferred to six traction motors in parallel connection, which drive the locomotive wheels to rotate through the traction gears, thus to make locomotive to run. Micro-computer excitation system is employed for the electric drive system of the locomotive for power regulation. The startup of diesel engine is accomplished through the starter-generator. After the starter-generator is switched to power-generation mode, it provides power supply for battery charge and auxiliary power consumption of the locomotive [12]. Figure 3.1shows block diagram.

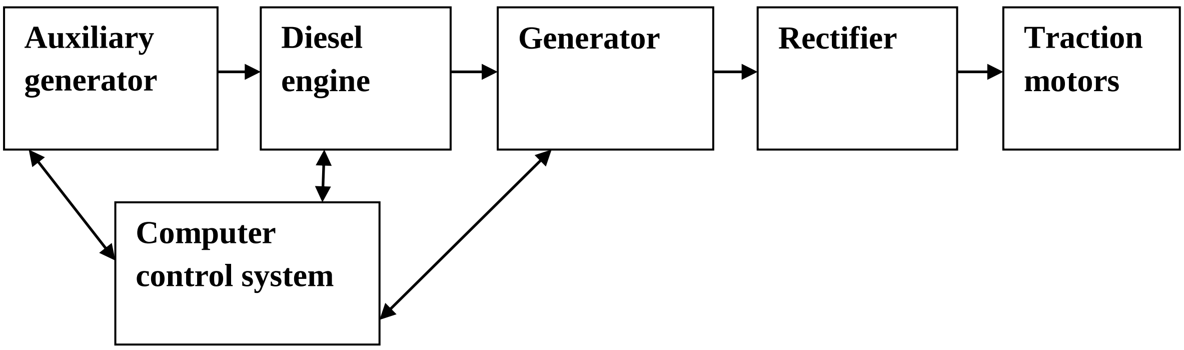


Figure 3.1: Block diagram of case study 1

3.2.1 Auxiliary generator (DC DYNASTARTER)

Being a power supply of the starting power of diesel and the auxiliary electrical equipment (including accumulator charging). Dynastarter is specially designed for the diesel locomotive. When starting a diesel engine, the electrical motor is supplied by battery as series motor operation. After starting the diesel engine, the electrical motor is driven by diesel engine and operated as a generator by switching on the winding. The control of terminal voltage of generator done is by adjusting separate excitation current and the adjustment of separate excitation current is by using voltage regulator of the excitation circuit [12].

3.2.2 Diesel engine

The 3500B series engines with Electronic Unit Injectors (EUIs) option are electronically controlled engines. The engines have ECM and electronic fuel injectors. The engines are equipped with either Jacket Water After Cooling (JWAC) or Separate Circuit After Cooling (SCAC). There are several engine models available: 8 cylinders, 12 cylinders and 16 cylinders. The specifications of the 12 cylinder (3512B) are listed in Table 3.1.

Table 3.1: the specifications of the 12 cylinder (3512B)

Cylinders and arrangement	60 degree Vee 12
Bore	170 mm (6.7 inch)
Stroke	190 mm (7.5 inch)
Type	4 stroke cycle
Compression ratio	14:1
Displacement per cylinder	4.3 L (263 cu in)
Total displacement	51.8 L (3158 cu in)

3.2.3 The ECM system

This system provides greater ability for precise measuring, data processing, operating environment flexibility and analysis to ensure efficient diesel engine operation. The ECM system is divided into these main groups of components:

- Electronic sensors: use to monitor engine operating conditions and changes and relay that information back to the ECM. A wide array of physical inputs is converted into electrical signal outputs.
- Actuators or solenoids: which convert the control unit's electrical output signal sent by ECM into mechanical control movement.

ECM with microprocessors, memory units, analog to digital converters and output interface units: which process information from various sensors in accordance with programmed software and outputs required electrical signals into actuators and solenoids [1]. Figure 3.2 shows the ECM system.

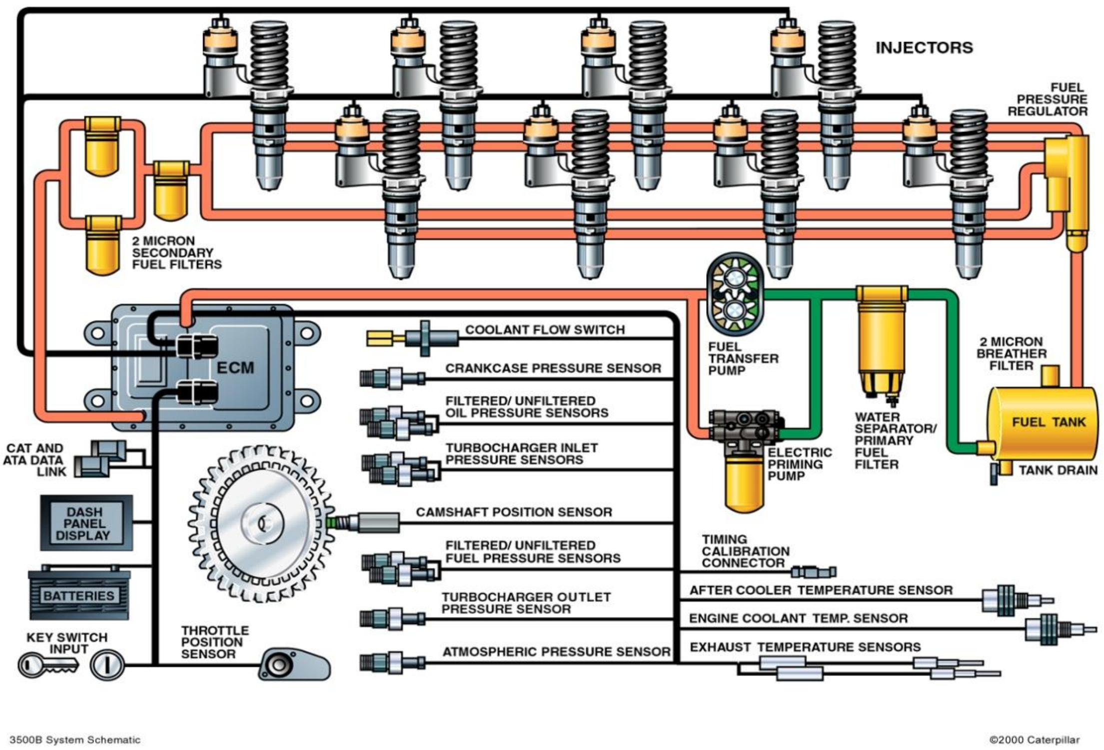


Figure 3.2: ECM system

The main advantages of ECM are:

- Meter the appropriate quantity of fuel, as demanded by the speed off, and the load on, the engine at the given time.
- Distribute the metered fuel equally among cylinders in a multi-cylinder engine.

- Inject the fuel at the correct time (with respect to crank angle) in the cycle.
- Inject the fuel at the correct rate (per unit time or crank angle degree).
- Inject the fuel with the correct spray pattern and sufficient atomization as demanded by the design of the combustion chamber.
- Caterpillar Electronic Technician (Cat ET) is a service tool designed to run on a Personal Computer (PC) under Microsoft Windows. With Cat ET you can display the status of a group of parameters (temperatures, pressures, etc.) simultaneously, view and clear active and logged diagnostic, or display the current configuration of an ECM. Cat ET can perform these as well as many other tasks, such as:
    - Display, graph, and record logs of parameter status.
    - View and clear diagnostics.
    - View events where irregularities occurred and were logged by the ECM.
    - View and change configuration of the ECM.
    - Perform diagnostic tests.
    - Perform calibrations.
    - View Trip information through Trip summary, Histograms and Custom reports.
    - Print reports and diagnostic results.

The main disadvantages of ECM are:

- ECM combines and controls all the task related with engine operation. So there is no way to customize or control any of the operation separately like fuel control or air-fuel mixture tuning except the pre-programmed presets.
- ECM cannot be modified for further customization. Only authorized after market ECM can be the solution for further modification.
- Repair work and tempering is not fruitful on ECM.

- It is an expensive device and technology. It makes any engine more costly [13].

3.2.4 Generator

This alternator is brushless synchronous main generator with self-ventilation, double-shaft extension, three-phase salient pole. There is a cylindrical roller bearing on the input end with shaft extension, which is used for linking diesel engine end. The generator is of axial self-ventilation. The cooling air is imbibed from the air inlets of end bracket after cool the machine and is exhausted through centrifugal fan and out of air outlet of the frame [14].

3.2.5 Rectifier

The Silicon Rectifier Device (SRD) is the commutation equipment for the main circuit of locomotive, it can convert the 3-phase AC emitted by the traction synchronous generator into pulsating DC**,** to supply to the traction motor. It consists of cabinet body, AC copper bar, DC bus bar, silicon rectifying cell, connecting conductor, resistance capacitance, the 3-phase AC input bus bar enters from the upper part of the rectifier device, the output DC bus bar is led out at both sides of the lower part of the rectifier device.

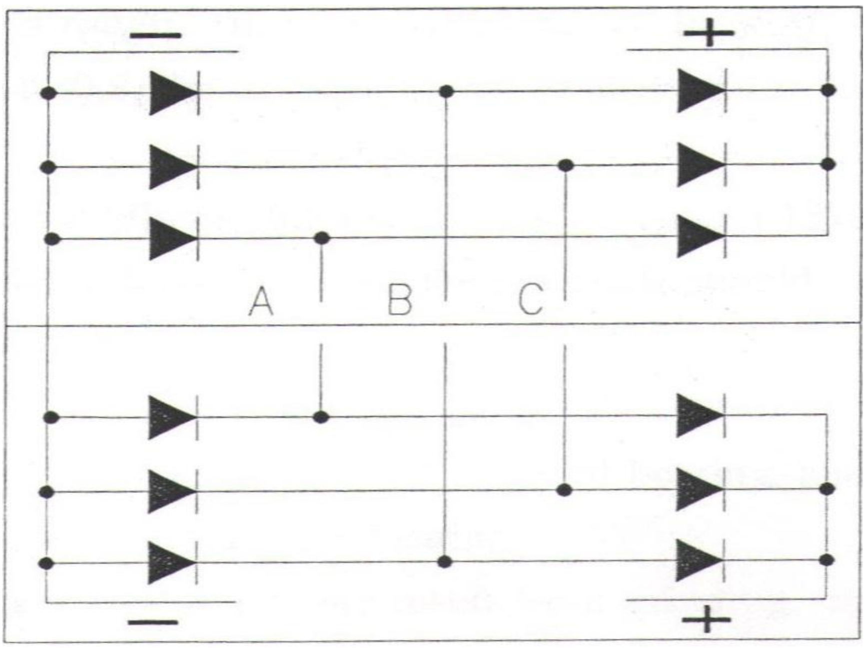


Figure 3.3: The circuit of the silicon rectifier device

Figure 3.3 shows the circuit of the silicon rectifier device. The silicon rectifier cabinet adopts forced draft cooling and heat dissipation method, first the silicon rectifier elements are cooled through both sides of the silicon rectifier device, then centrifugal ventilator will blow the motor to carry out cooling [14].

3.2.6 Traction motors:

Traction motor is a force-ventilated, four-pole, series-wound DC motor designed for narrow gauge diesel locomotive. It consists of stator, armature and brushholder assembly. Its normal function is to convert the electrical energy supplied by the generator into mechanical power for driving the locomotive wheels. The traction motor is coupled to the locomotive axle through a reduction gear system housed in a gear case.

- Stator:

The stator consists of frame, exciting pole commutating pole and flash ring. The exciting pole consists of frame is welded with press –formed steel plates. The exciting pole consists of exciting coil and core. The commutating pole consists of commutating coil and core.

- Armature:

The armature consists of armature core, shaft, armature coil, equalizer and commutator [14].

3.2.7 Computer control system

Along with the great progress of computer development and network technology, computer control system of locomotive has largely been broadened, which will not only realize higher performance of locomotive, but also lower operation cost. Figure 3.4 shows the control system.

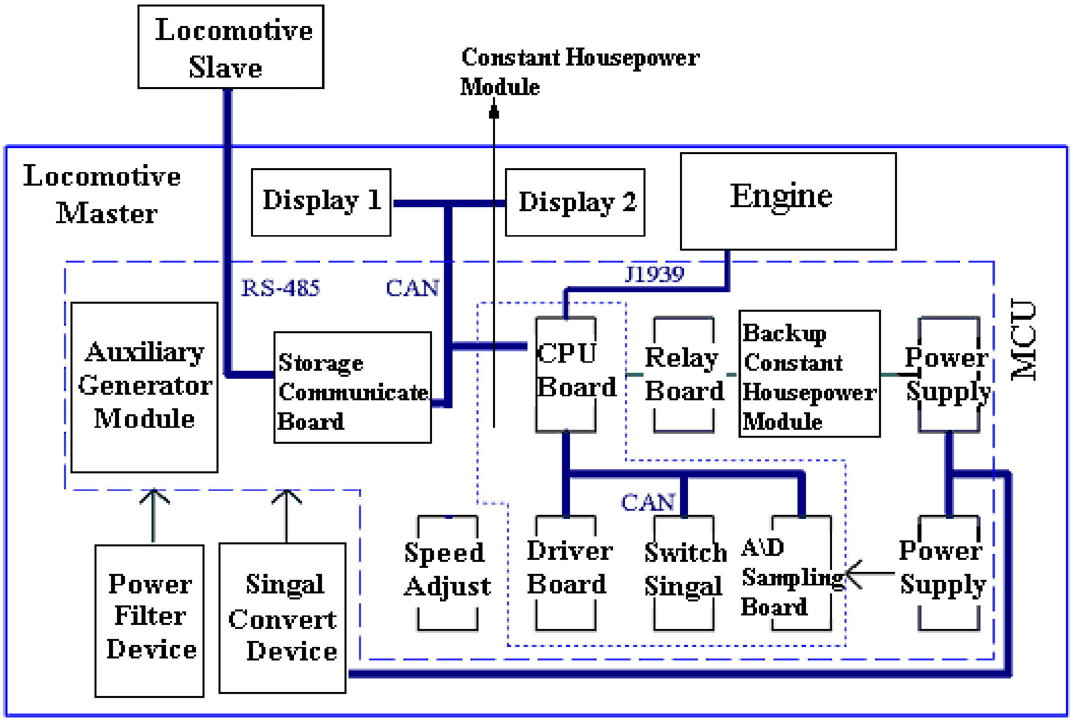


Figure 3.4: Control system

The functions of the system will be discussed below:

- Control constant horsepower of main generator.
- Dynamic control characteristics control.
- Auxiliary generator voltage control.
- Engine speed control.
- Main faults diagnosis and protection.
- Timely display locomotive running parameters.
- Communication between locomotive computer and engine's ECM.
- Display parameters of the multiple locomotives.

The computer control system of diesel locomotive is an electronic device controlled by computer, which is made up of computer control box, sensors, signal converter board, computer display screen and computer power supply and filter for computer power supply. It is used for the control of electric transmission of the locomotive. It is characterized by locomotive traction characteristics control, resistance brake characteristic control, diesel engine system protection, electric system protection, fault display and multi-unit control. This computer control system is connected to the locomotive circuit through four 62-pin rectangular plugs. There are sensor input circuit, signal converter circuit and the input/output circuit for analog switching variables. All signals from large power circuit are converted by the Signal Converting Device (SCD), then enter the computer, heighten the safety [15].

❖ Computer control box:

The boards of computer control box shows in Table 3.2.

Table 3.2: The board of computer control box

Name	Code
Power board	ZY200108
Auxiliary generator Voltage control board	ZY500205
Engine speed control board	ZY200102
Output board	ZY500206
Switch input board	ZY800203
A/D converting board	ZY200105
Main CPU board	ZY800204
Communication and storage board	ZY500209
Relay board	ZY200103

The boards of computer control box in Table 3.2 will be discussed below:

1. Power board:

Figure 3.5 shows the power board. The main features of power board are:

- Power supply for computer control system, which consists of (MCP, SCD ESM1B-ESM2A).
- Under the protection of over-current, over-heated and short-circuit with Light Emitted Diode (LED) indicator while running
- Widely input voltage, stably working between 40－140V.

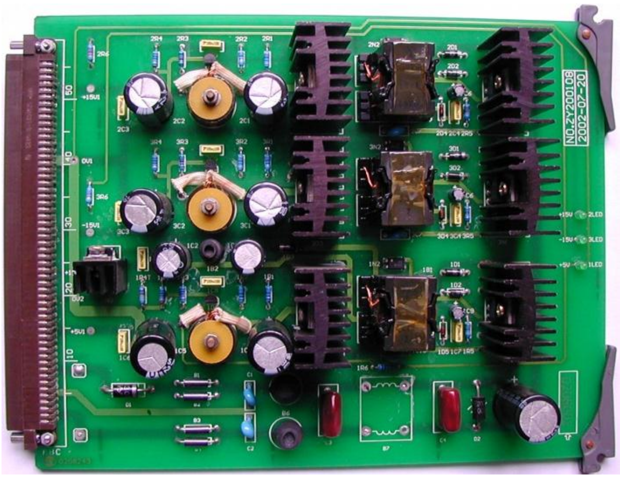


Figure 3.5: Power board

2. Auxiliary generator voltage control board:
   - Get feedback of auxiliary generator voltage and control the excitation of Auxiliary Generator to stabilize the voltage at 110 ±2V at different engine speed.
   - Protection of over-voltage.
   - Test of over-voltage.

Meaning of indicators:

LED1: Green normally bright.

LED2: Red, CMOS transistor on the board broken when bright.

LED3: Red, over-voltage when bright (over 125＋5V).

LED2, LED3: Bright at the same time means that the wire of voltage feedback broken or faults of excitation circuit (not fault when engine stops). Figure 3.6 shows the auxiliary generator voltage control board.

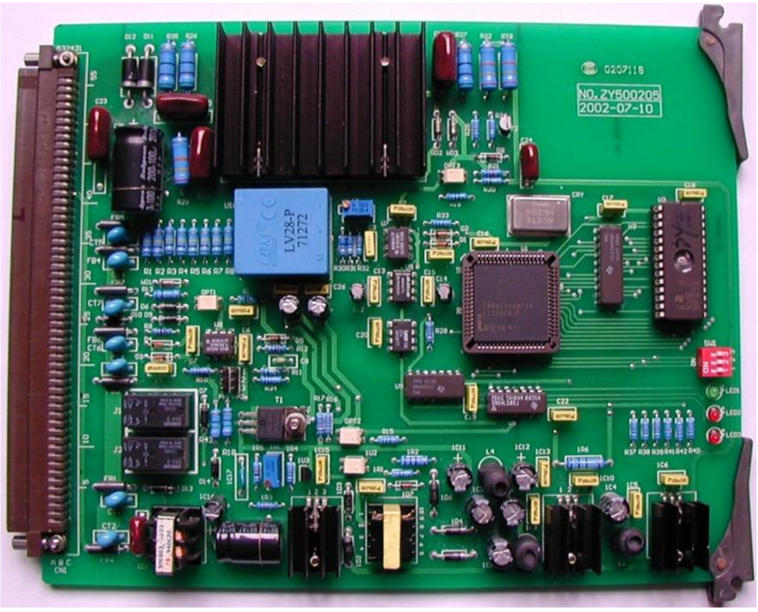


Figure 3.6: Auxiliary generator voltage control board

3. Engine speed control board:

   Figure 3.7 shows the engine speed control board. The main features of engine speed control board are:

   - According to the driver handle code, output 4-20mA.
   - Current signal to engine electrical eject sets.
   - Green LED: bright means working normally.

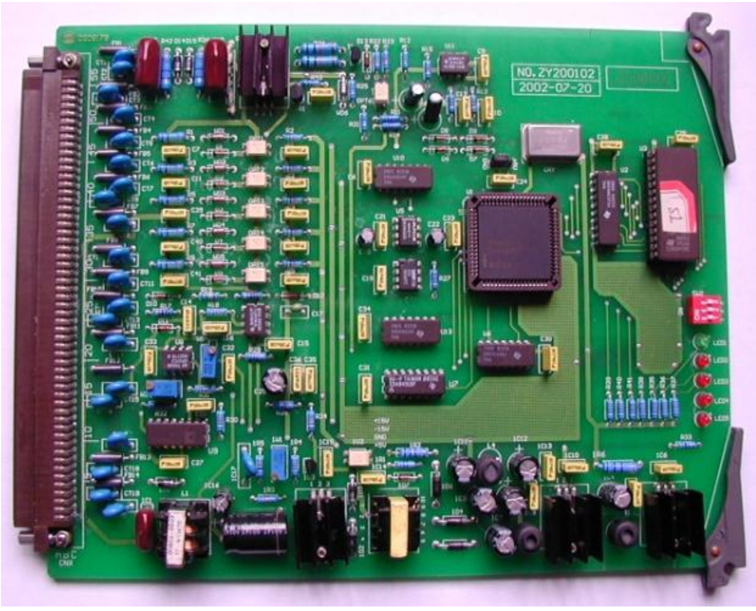


Figure 3.7: Engine speed control board

4. Output board:

   According to control signals from main CPU board, drive some of indicators on the driver’s desk, relay and chopper’s control. Figure 3.8 shows the output board.

   LED: Green, flickering means running normally.

Figure 3.8: Output board

5. Switch input board:

Detect switch signals and send them to the main CPU board by communication bus. This board can detect 32 switch signals. Figure 3.9 shows the switch input board.

LED: green, flickering means running normally.

Figure 3.9: Switch input board

6. A/D converting board:

This board can detect 16 analog signals and two frequency signals (engine speed, locomotive speed). Figure 3.10 shows the Analog /Digital (A/D) converting board. The main features of A/D converting board are:

- Detect analog signals and convert them into digital signals which computer can identify, then send them to the main CPU board by communication bus.
- LED: green, flickering means running normally.

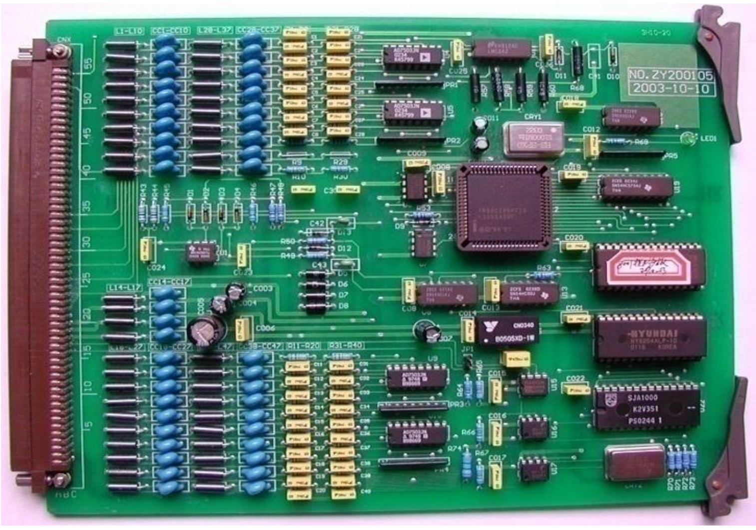


Figure 3.10: A/D converting board

7. Main CPU board:

Figure 3.11 shows the main CPU board. The main features of main CPU board are:

- Get information from each control board by Controller Area Network (CAN) bus, process them and then send out instructions.
- Communication between engines'ECM and locomotive computer.

Indicators:

LED1, LED2: green,flickering means running normally.

Figure 3.11: Main CPU board

8. Communication and storage board:

Store malfunction information and locomotive's important parameter. Carry out the communication between by RS485 communication bus [15]. Figure 3.12 shows the communication and storage board.

Figure 3.12: Communication and storage board

9. Relay board:

Realize the power transference between NORMAL and STANDBY constant horsepower control modules, i.e.＋5V, ＋15V, －15V, －110V, ＋110V. Figure 3.13 shows the relay board.

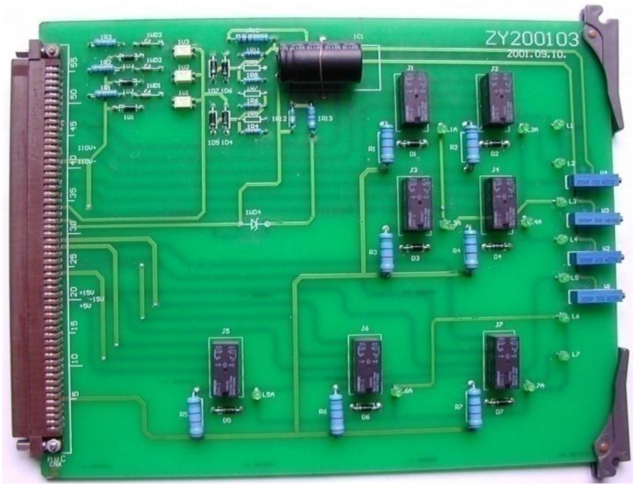


Figure 3.13: Relay board

❖ Signal converting device:

This system includes two Signal Converting Devices (SCD) ESM1A and ESM2A. Each one converts the locomotive's corresponding signals to 0-5V and then sends these signals to the computer controller unit for processing.

▪ SCD -ESM1A:

Figure 3.14 shows the SCD - ESM1A. The main features of SCD ESM1A are:

- High isolation class to realize high safety of the system.
- Transfer current of motor (mV) to 0－5V.

- Isolate engine speed, locomotive speed between locomotive and computer.
- Transfer engine load feedback signal (mA) to 0—5V.

Figure 3.14: SCD - ESM1A

▪ SCD– ESM2A:

Figure 3.15 shows the SCD – ESM2A. The main features of SCD ESM2A are:

- High isolation class to realize high safety of the system.
- Transfer current of motor (mV) to 0—5V.
- Transfer voltage of main Generator, current of main Generator, excitation current of traction motors to 0—5V.

Figure 3.15: SCD – ESM2A

❖ Computer display screen:

Figure 3.16 shows computer display screen. The functions of monitor are:

- Good human-machine interface (HMI).
- According to the communication protocol , carry out the communication between the monitor and the computer control system.
- Display locomotive's real-time running parameters and malfunction.
- Set up of important parameters.
- Display both master and slave locomotive's running parameters of multiple connected locomotives.

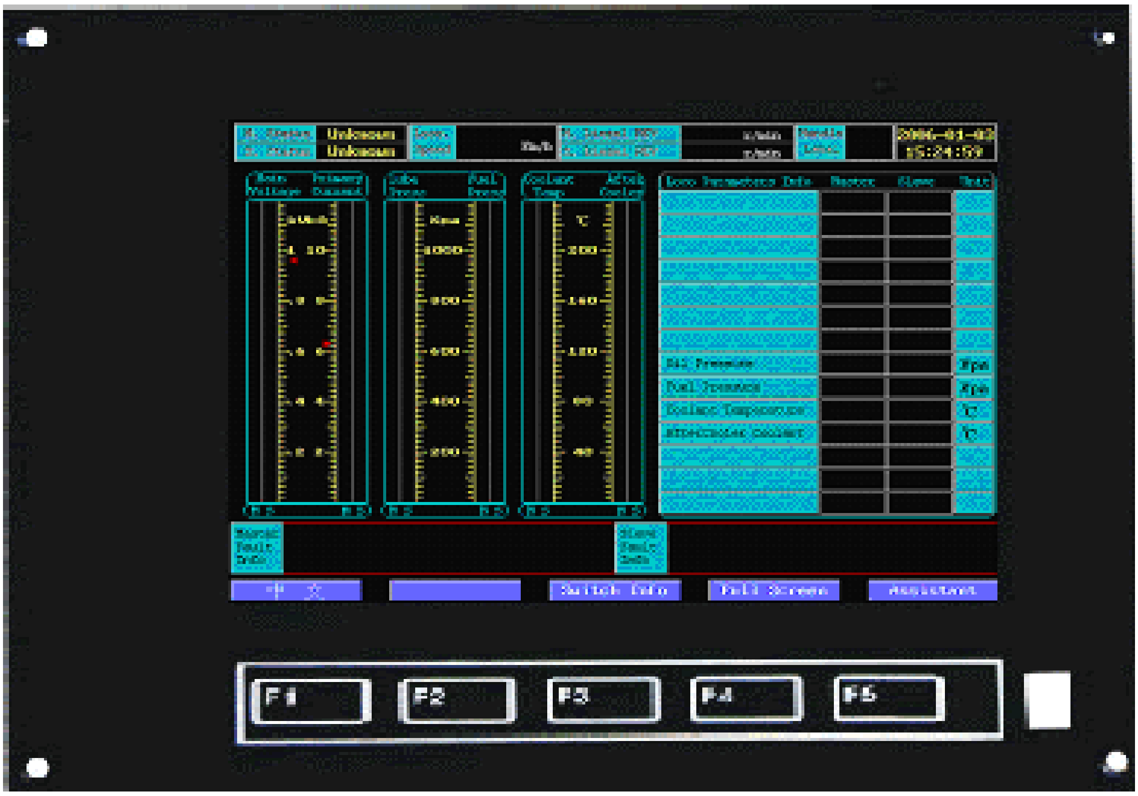


Figure 3.16: Computer display screen

❖ Power filter:

Improve the quality of 110V power supply of the control system, prevent the system from the damage caused by higher ripple voltage of locomotive's 110V power supply [16]. Figure 3.17 shows the power filter.

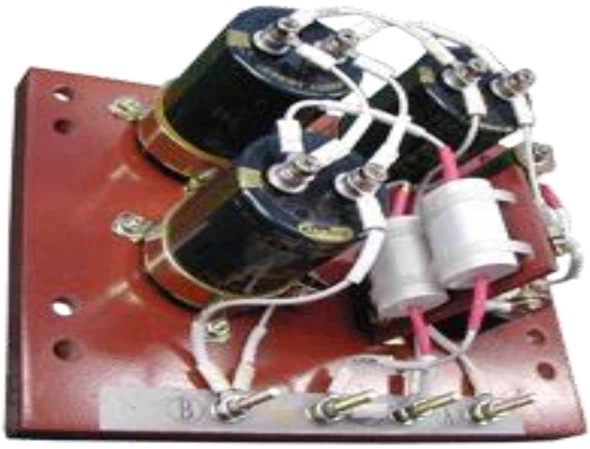


Figure 3.17: Power filter

3.3 Case Study (2)

The internal combustion locomotive is designed as DC-DC electrically driven locomotive, with the diesel engine manufactured by General Electric (GE) type 7FDL (this engine is the prime-mover in the locomotive under study) driving a generator(referred to as main generator). The output current generated by the main generator, is supplied to six traction motors in parallel connection, which drive the locomotive wheels to rotate through the traction gears, thus to make locomotive to run. Mechanical governor is employed for the electric drive system of the locomotive for power regulation. The startup of diesel engine is accomplished through the starter-generator. After the starter-generator is switched to power-generation mode, it provides power supply for battery charge and auxiliary power consumption of the locomotive. Figure 3.18 shows block diagram.

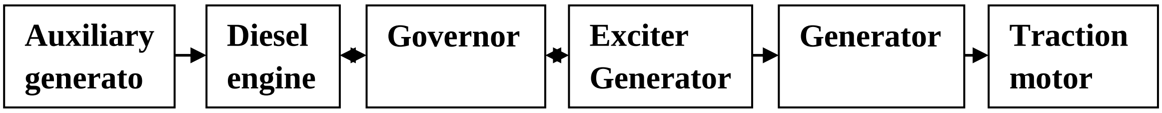


Figure 3.18: block diagram of case study 2

The flowing units are common in both systems (auxiliary generator and traction motor) was discussed in case study 1.

3.3.1 Diesel engine

The GE (General Electric) 7FDL is a series of four-stroke prime-movers or diesel engine (motor) models. They consist of 8, 12 and 16 cylinder configurations, and are typically arranged in a "V" formation like many other prime-movers built for diesel locomotives [17]. The specifications of GE7FDL8 engine are show in Table 3.3.

Table 3.3 the specifications of the GE 7FDL8 (8 cylinder) engine:

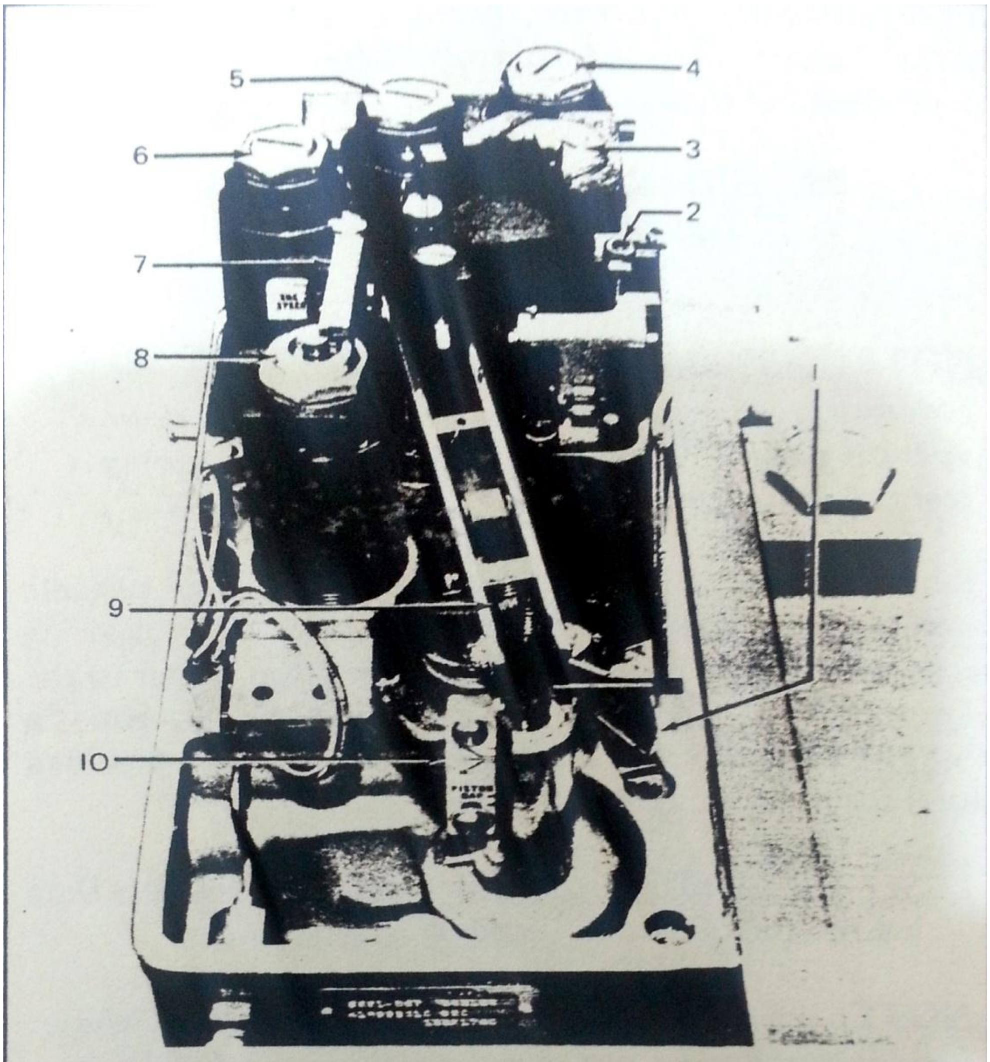
Cylinders and arrangement	45 degree Vee8
Bore	228.6 mm (9 inch)
Stroke	266.7 mm (10.5 inch)
Type	4 stroke cycle
Compression ratio	12.7:1
Displacement per cylinder	10.7 L (667 cu in)
Total displacement	85.5 L (5341 cu in)

3.3.2 Engine control governor

The engine control governor is an electrohydraulic device used to regulate speed and horsepower output on the diesel engine. It also includes a number of auxiliary devices to protect and provide the power plant with characteristics desirable for railway locomotive service. The governor is a self-contained unit which is mounted on and driven by the diesel engine. It is equipped with its own oil supply and oil pressure pump and is remotely controlled by the locomotive throttle.

During operation the governor performs two basic functions. Primarily, it controls the speed of the diesel engine by regulating the amount of fuel supplied to the engine cylinders. At any speed setting of the governor, speed control is isochronous; that is, the governor maintains constant engine speed regardless of changing conditions of load. The secondary function of the governor is to maintain a constant predetermined horsepower output of the engine for each specific speed setting by accurately controlling the engine load. Control of the engine load is accomplished by adjusting the strength of the generator field to compensate for electrical load changes on the generator and those resulting from variable auxiliary loads such as the air compressor, battery charging generator, etc. Thus, while the primary functions of the governor is to maintain speed of the engine, by controlling both speed and load, condition of balance can be established which results in a constant, single horsepower output for each speed setting of the engine. The basic governor parts are:

1. The base which encloses the bottom of the governor and supports the governor drive shaft assembly.
2. The power case containing the oil supply, oil pressure pump and pressure accumulators, as well as the buffer cylinder and main pilot valve assemblies.
3. The column containing the rotating flyweight head, speeder spring, speed setting servo assembly, as well as the speed setting pilot valve and load control pilot valve assemblies. Mounted to the top of the column are the electric speed setting solenoids designated A, B, C and D and the overriding solenoid marked O. Enclosed within the cover at the top of the governor column are levers and linkage which interconnect various other functional parts. Figure 3.19 shows the solenoids of governor.
4. The power cylinder assembly which is fastened to the front side of the power case contains the power piston, piston spring and the compensating needle valve. The power cylinder, through its piston and spring, furnishes the controlled mechanical force required to move the control rack on each fuel injection pump.
5. The load control potentiometer and servomotor assembly is attached to the right side of the governor column. It is used to change the value of resistance in the generator excitation circuit. This assembly consists of an electrical resistance unit having a commutator-type selector switch and a pair of contact brushes which are driven by the vane servomotor. Position and movement of the vane servomotor shaft and the contact brushes are controlled by the load control pilot valve, which selects the correct value of resistance required to balance the load at each speed setting of the engine [17].



REF.	DESCRIPTION
1	LOAD-CONTROL INDICATOR SCALE
2	FUEL-LIMIT ADJUSTING SCREW
3	"C" SOLENOID
4	"A" SOLENOID
5	"D" SOLENOID
6	"B" SOLENOID
7	OVERRIDING-SOLENOID LEVER
8	OVERRIDING SOLENOID
9	LOAD-CONTROL ADJUSTING SCREW
10	POWER-PISTON GAP INDICATOR

Figure 3.19: The solenoids of governor

- Description of operation:

The governor drive shaft passes through the governor base into the pump drive gear which is directly connected to the rotating pilot valve bushing. The flyweight head is secured to the upper end of the pilot valve bushing, providing a direct drive from the engine to the flyweights. At any speed setting of the governor when the engine was "on-speed", the centrifugal force of the flyweights will balance the opposing force of the speeder spring with the flyweights in the vertical position. The control land of the pilot valve plunger will be covering the regulating ports in the rotating pilot valve bushing.

Pressure seal grooves A, B and C are supplied with pressure oil through the regulating port. This prevents the oil trapped between the power piston and the buffer piston from leaking past the power piston rod and pilot valve stem. To make up for leakage of the seal oil and hold the power piston in a steady position against the power spring when the engine is "on-speed" with a steady load, the pilot valve plunger will be enough below center to supply the required amount of oil through the
regulating port.

The governor pump supplies pressure oil to the accumulators and rotating pilot valve bushing. Movements of the power piston are transmitted by the piston rod to the fuel injection pumps on the engine. Regulated oil pressure under the power piston is used to raise the power piston to increase fuel. The power spring above the power piston is used to lower the power piston to decrease fuel [17].

3.3.3 Exciter generator

The exciter generator is a four-pole, self-ventilated induction machine which converts mechanical energy into electrical power. The electrical power, in turn, excites the main traction generator. The function of the exciter, in conjunction with the control system, is to maintain constant horsepower output of the main generator over a wide range of load.

3.3.4 Generator

The generator is a ten-pole, shunt-wound, horizontal-shaft machine that converts mechanical energy from the diesel engine into electrical power to drive traction motors. The generator has a starting winding that enables it to run as a series motor. When energized with direct current, the generator produces mechanical energy to crank the diesel engine. The commutator end of the generator armature is supported by a cylindrical roller bearing, and the coupling end is supported by the diesel-engine crankshaft.

CHAPTER FOUR

SIMULATION AND COMPARISON

4.1 Simulation Result

A comparative study between case study 1 and case study 2 has been done here. The simulation tests are based on the facts that whether the case study 1 is better than the case study 2 or not. The simulation procedure may be summarized as follows:

- The case study 1 data has been entered.
- The case study 2 data has been entered.

Figure 4.1 shows the speed and power carve of two cases.

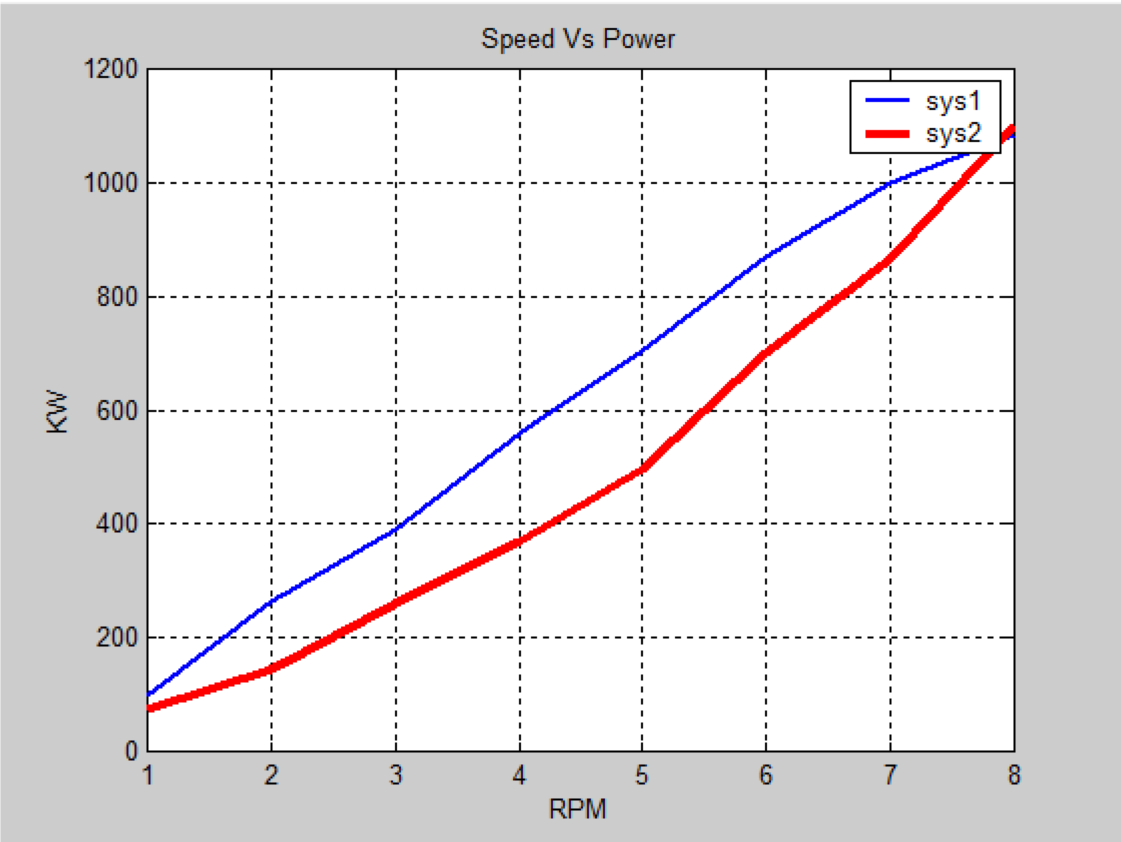


Figure 4.1: Speed and power carve of two cases

4.2 Comparison

Figure 4.1 shows the speed and power of the two systems. The obtained results showed that system 1 has higher power than system 2. Comparison between engine of case study 1 (using electronic control module (3512B)) and engine of case study 2 (using mechanical control governors (GE 7FDL8)) is illustrated in table 4.1.

Table 4.1 Comparison between 3512B and GE 7FDL8

	3512B (12 Cylinder)	GE 7FDL8 (8 Cylinder)
Stroke Cycle	4	4
Fuel Type	Gasoline	Gasoline
Engine Type	Caterpillar	General electric
Cooling System	Water	Water
Injection Type	Electronic fuel injector	Reciprocating fuel pump
Displacement	51.8L(3158 cu in)	85.5L(5341 cu in)
Fuel Consumption	3.6 liter/Km	4.5 liter/Km

The main deference is injection type, case 1 the injection is through electronic fuel injector and case 2 the injection type is reciprocating fuel pump.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1Conclusion

The performance of the electronic control governor and embedded system (system 1) and mechanical governor system (system 2) were validated through simulations based on the comparative simulation results. The MATLAB simulation result shows that system 1 has high power as compared to system 2. The fuel consumption in system 1 lower than system 2 as showed in table 4.2, also the displacement in system 1 is 51.8 liter and in system 2 about 85.5 liter The comparison between the two systems shows clearly that the electronic control governor and embedded system gives better performances than mechanical governor system .

5.2 Recommendations

The electronically-control is widely used in industrial applications, because of their high reliability, flexibility and low cost. This work can be developed using:

- Programmable Logic Controller (PLC).
- Fuzzy logic control.
- Neural networks.

All three approaches are interesting and very promising area of research and development.

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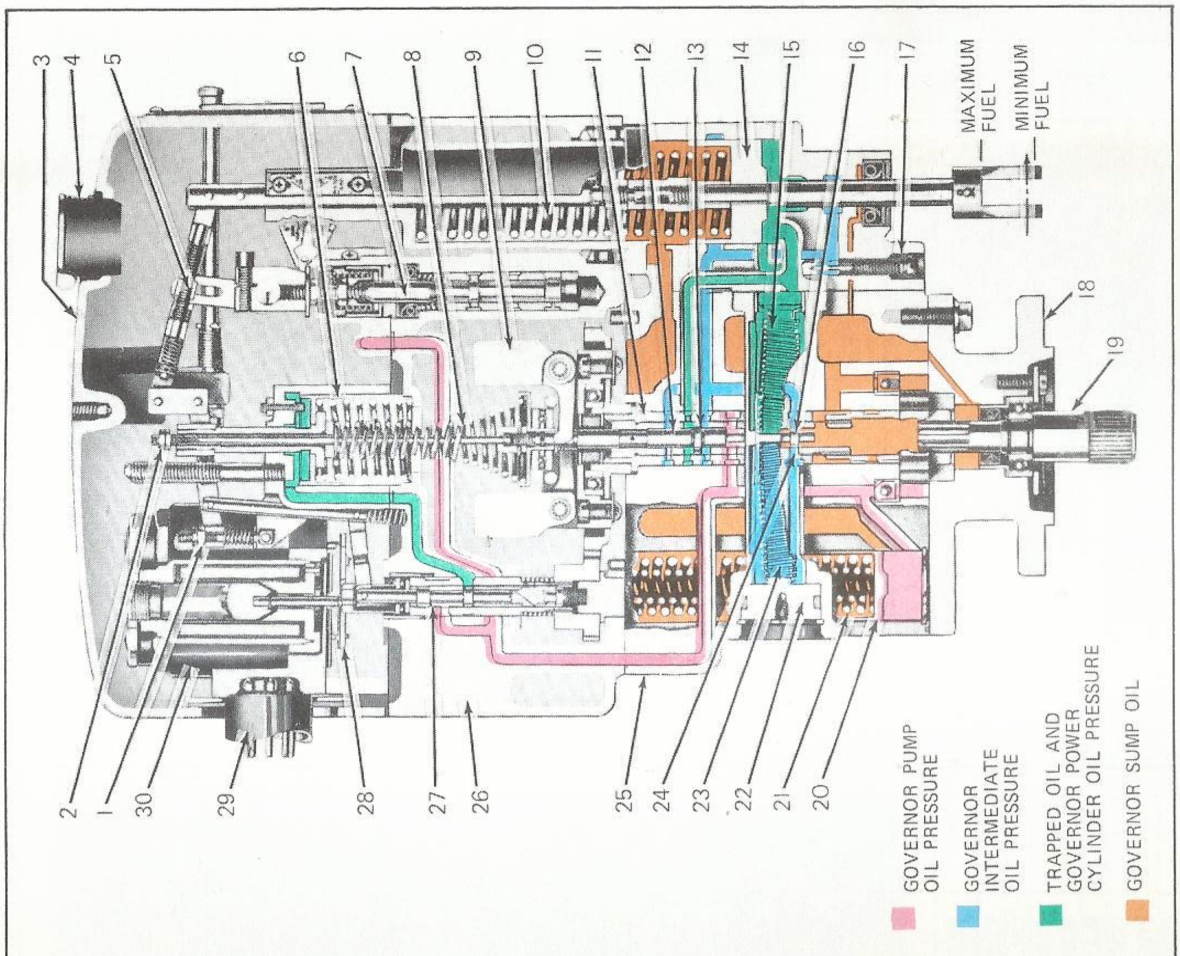
APPENDIX

MATLAB (m file) FOR POWER AND SPEED OF ENGINE

```
x=[1,2,3,4,5,6,7,8]
y=[100,263,392,560,705,869,1001,1084]
z=[75,145,260,371,497,701,864,1100]
plot(x,y,'b','linewidth',2)
grid on
hold on;
plot(x,z,'r','linewidth',3)
grid on
legend('sys1','sys2')
title('Speed Vs Power')
xlabel('RPM')
ylabel('KW')
```

APPENDIX B

BASIC GOVERNOR PARTS



REF.	DESCRIPTION
1	BASE SPEED SETTING NUT
2	SHUTDOWN ROD AND NUTS
3	COVER
4	OIL FILLER CUP
5	LOAD CONTROL LINKAGE
6	SPEED SETTING CYLINDER AND PISTON
7	LOAD CONTROL PILOT VALVE
8	SPEEDER SPRING
9	FLYWEIGHTS
10	POWER SPRING
11	PILOT VALVE BUSHING
12	PILOT VALVE PLUNGER
13	COMPENSATING LAND ON PILOT VALVE
14	POWER PISTON
15	BUFFER SPRING
16	CONTROL LAND
17	COMPENSATING NEEDLE VALVE
18	BASE
19	DRIVE SHAFT
20	ACCUMULATOR PISTON
21	ACCUMULATOR SPRINGS
22	BUFFER CYLINDER PLUG
23	BUFFER SPRING
24	REGULATING PORT
25	POWER CASE
26	COLUMN
27	SPEED SETTING PILOT VALVE
28	TRIANGULAR PLATE
29	ELECTRICAL CONNECTOR
30	SPEED SETTING SOLENOIDS A-B-C-D