Stamford University Bangladesh

Department of Electrical and Electronic Engineering

Thesis on

"***Study of Engine and Alternator Control System of Captive Power Plant.***"

A thesis report submitted to the Department of Electrical and Electronic Engineering, Stamford University Bangladesh, in partial fulfillment of the requirement for the degree of "Bachelor of Science in Electrical and Electronic Engineering".

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DECLARATION

It is hereby declared that the thesis report titled "***Study of Engine and Alternator control System of Captive Power Plant .***" Presented to the department of the investigation carried out by us under the supervision of **Dr. Enamul Basher**, Chairman, Department of Electrical and Electronic Engineering, Stamford University Bangladesh.

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Dedication

This is for our exclusive parents for keeping us in school and for our supervisor Professor Dr. Enamul Basher for his enormous support and encouragement. It’s also for our friends for keeping us happy in our mental faculty.

ACKNOWLEDGEMENT

First of all we articulate our gratitude to almighty Allah to enable us to complete the thesis. And then we express our sincere appreciation and heartfelt thanks to our respected supervisor. We must feel grateful to & wish our acknowledgement our proud indebtedness to Professor Dr. Enamul Basher(Chairman, Department of Electrical & Electronic Engineering, Stamford University Bangladesh). His deep knowledge & help us to carry out the project up to this point. Their endless patience, scholarly guidance, continual encouragement, constant & energetic supervision, constructive criticism, valuable advice, supplying necessary documents, reading many inferior drafts & correcting them at all circumstances have made it possible to come to this stage.

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ABSTRACT

This paper discloses about whole Power Generation Structure of Bangladesh, daily demand of DESCO, DPDC, BPDB. We also try to find out: why is the crisis in power generation in Bangladesh and its solution, why is the Captive Power generation necessary? What kinds of Power plants are suitable for captive Power Generation in Bangladesh? Diesel Engine Power Plant Vs Gas Engine Power plant with mathematical analysis. This thesis also includes the Necessity of power plant, History of power plant .It deals with brief discussion about different parts of ENGINE, Its control system (i.e. Lambda control, Ignition control),different trouble shooting and its causes as well as remedies. Last but not a least. We discuss the different parts of AC Generator system and its protective system. This paper deals with ignition control, or more specifically with spark advance control, i.e. how long before top dead center (TDC) to ignite. The idea is to control the spark advance so that the pressure peak is placed relative to TDC in an optimal way. Work is lost to compression and heat transfer if it is placed too eaxly, and expansion work is lost if it is placed too late. A key problem is thus to find a description of the ionization current that is rich enough to capture the different variations, but still such that the relevant information can be extracted.

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History and Development of power plant

Introduction

ENERGY is the basic necessity for the economic development of a country. Many functions necessary to present day living grind to halt when the supply of energy stops. It is practically impossible to estimate the actual magnitude of the part that energy has played in the building up the present-day civilization. The availability of huge amount of energy in the modern times has resulted in a shorter working day, higher agricultural and industrial production healthier and more balanced diet and transformation facilities. As a matter of fact, there is a close relationship between the energy used per person and his standard of living. The greater the per capita in consumption of energy in a country, the higher is the standard of living of its people.

Captive power plant installation is one the most contributing step for Bangladesh Govt as we know that is to a developing country. Power generation projects are the most capital-intensive infrastructural investments. Plant development and operation requires planning, designing and economic terms not purely with technical mindset investment .Decisions made today will form our lives for tomorrow that's way we should to do something for next generation. Many functions necessary to present-day living regrind to a halt when the energy supply stops.

Mechanical and Electrical energy are manufactured commodities just like tangible items such as clothing, furniture, or tools. All manufacturing activity processes raw materials as found in nature into forms more useful for human use. Production of electrical and mechanical energy is similar; entailing the processing of natural raw forms of energy at the instant it is needed. The entire process takes only a fraction of a second. This instantaneous production introduces technical, economical, and political considerations unique to the electric power industry.

But it not develops in a single day. Many scientists, engineers work hard to stabilize it .That we would like to discuss it sequentially. To point of view we decide our Thesis Topics is" *Study of Engine and Alternator Control System of Captive Power Plant.*"

1.1 History of power Generation:

Centralized power generation became possible when it was recognized that alternating current power lines can transport electricity at very low costs across great distances by taking advantage of the ability to raise and lower the voltage using power transformers.

The fundamental principles of electricity generation were discovered during the 1820's and early 1830's by the British scientist Michael Faraday. His basic method is still used today: electricity is generated by the movement of a loop of wire, or disc of copper between the poles of a magnet.

Electricity has been generated at central stations since 1881. The first power plants were run on water power or coal and today we rely mainly on coal, nuclear, natural gas, hydroelectric, and petroleum with a small amount from solar energy, tidal harnesses, wind generators, and geothermal sources.

1.2 History of Power Generation in Bangladesh:

Electric power is generated by a hydroelectric complex in the Chittagong Hills and thermal plants in Chittagong and several locations in central and western Bangladesh. In 1987 the government announced its intention to proceed with construction of its first nuclear power facility, having concluded that the country's long-term needs could not be met by continued reliance on natural gas reserves. They did not announce how the project would be financed, but West Germany was considered the most likely source. The country's total generating capacity was 1,141 megawatts as of 1986, and the proposed nuclear plant would add between 300 and 400 megawatts.

Electric power outages and restrictions on peak-period consumption were a serious problem in the mid-1980s, resulting in substantial productivity losses for jute, textile, and other industrial concerns. Government and power board authorities worked out a strategy of planned brownouts and shutdowns, which were distributed geographically as equitably as possible to minimize economic disruption. Some industrial concerns adopted off-peak work schedules, operating their factories in the middle of the night instead of in the daytime.

There were also substantial losses in the transmission and distribution of electric power, including many unauthorized hookups to the system. The urban distribution system found it difficult to persuade subscribers, including state-owned industries, to pay their bills. In contrast, the system of rural electrification cooperatives, established in the late-1970s with assistance from the United States and other donors, and gradually expanding since then, has demonstrated that it is possible to deliver electric power effectively to nonurban consumers. Rural electrification immediately transforms economic life: within weeks a profusion of consumer goods appears, night markets open (complete with tiny cinemas for audiences of fifteen or twenty people), and demand for electric irrigation pumps soars.

1.3 Electricity generation:

Electricity generation is the process of creating electricity from other forms of energy. Electricity is produced at an electric power plant. Some fuel source, such as coal, oil, natural gas, or nuclear energy produces heat. The heat is used to boil water to create steam. The steam under high pressure is used to spin a turbine. The spinning turbine interacts with a system of magnets to produce electricity. The electricity is transmitted as moving electrons through a series of wires to homes and business.
For electric utilities, it is the first process in the delivery of electricity to consumers. The other processes, electric power transmission, electricity distribution, and electrical power storage and recovery using pumped storage methods are normally carried out by the electrical power industry. Electricity is most often generated at a power station by electromechanical generators, primarily driven by heat engines fueled by chemical combustion or nuclear fission but also by other means such as the kinetic energy of flowing water and wind. There are many other technologies that can be and are used to generate electricity such as solar photovoltaic and geothermal power.

1.4 Fundamental Methods of Generating Electricity:

There are seven fundamental methods of directly transforming other forms of energy into electrical energy:

1. Static electricity, from the physical separation and transport of charge Examples: turboelectric effect and lightning
2. Electromagnetic induction, where an electrical generator, dynamo or alternator transforms kinetic energy (energy of motion) into electricity
3. Electrochemistry, the direct transformation of chemical energy into electricity, as in a battery, fuel cell or nerve impulse
4. Photoelectric effect, the transformation of light into electrical energy, as in solar cells
5. Thermoelectric effect, direct conversion of temperature differences to electricity, as in thermocouples and thermopiles
6. Piezoelectric effect, from the mechanical strain of electrically anisotropic molecules or crystals
7. Nuclear transformation, the creation and acceleration of charged particles Examples: photovoltaic or alpha particle emission

Almost all commercial electrical generation is done using electromagnetic induction, in which mechanical energy forces an electrical generator to rotate. There are many different methods of developing the mechanical energy, including heat engines, hydro, wind and tidal power.

The direct conversion of nuclear energy to electricity by beta decay is used only on a small scale. In a full-size nuclear power plant, the heat of a nuclear reaction is used to run a heat engine. This drives a generator, which converts mechanical energy into electricity by magnetic induction. Most electric generation is driven by heat engines. The combustion of fossil fuels supplies most of the heat to these engines, with a significant fraction from nuclear fission and some from renewable sources.

Modern technology uses large amounts of electrical power. This is normally generated at power plants which convert some other kind of energy into electrical power. Each such system has advantages and disadvantages, but many of them pose environmental concerns. The efficiency of some of these systems can be improved by cogeneration (combined heat and power) methods. Process steam can be extracted from steam turbines. Waste heat produced by thermal generating stations can be used for space heating of nearby buildings.

1.5 Sources of Electrical Energy:

Electrical energy occurs naturally, but seldom in forms that can be used. For example, although the energy dissipated as lightning exceeds the world's demand for electricity by a large factor, lightning has not been put to practical use because of its unpredictability and other problems. Generally, practical electric-power-generating systems convert the mechanical energy of moving parts into electrical energy as like generator. While systems that operate without a mechanical step do exist, they are at present either excessively inefficient or expensive because of a dependence on elaborate technology. While some electric plants derive mechanical energy from moving water (hydroelectric power), the vast majority derive it from heat engines in which the working substance is steam. Roughly 89% of power in the United States is generated this way. The steam is generated with heat from combustion of fossil fuels or from nuclear fission.

1.6 Generation methods:

Various other technologies have been studied and developed for power generation. Solid-state generation (without moving parts) is of particular interest in portable applications. This area is largely dominated by thermoelectric (TE) devices, though thermionic (TI) and thermo photovoltaic (TPV) systems have been developed as well. Typically, TE devices are used at lower temperatures than TI and TPV systems. Piezoelectric devices are used for power generation from mechanical strain, particularly in power harvesting. Photovoltaic are another type of solid-state power generator which produces electricity from radioactive decay. Fluid-based magneto hydrodynamic (MHD) power generation has been studied as a method for extracting electrical power from nuclear reactors and also from more conventional fuel combustion systems. Osmotic power finally is another possibility at places where salt and sweet water merges.

Electrochemical electricity generation is also important in portable and mobile applications. Currently, most electrochemical power comes from closed electrochemical cells ("batteries"), which are arguably utilized more as storage systems than generation systems, but open electrochemical systems, known as fuel cells, have been undergoing a great deal of research and development in the last few years. Fuel cells can be used to extract power either from natural fuels or from synthesized fuels (mainly electrolytic hydrogen) and so can be viewed as either generation systems or storage systems depending on their use.

1.6.1 Steam:

The conversion of mechanical energy to electrical energy can be accomplished with an efficiency of about 80%. In a hydroelectric plant, the losses occur in the turbines, bearings, penstocks, and generators. The basic limitations of thermodynamics fix the maximum efficiency obtainable in converting heat to electrical energy. The necessity of limiting the temperature to safe levels also helps to keep the efficiency down to about 41% for a fossil-fuel plant.
Most nuclear plants use low-pressure, low-temperature steam operation, and have an even lower efficiency of about 30%. Nuclear plants have been able to achieve efficiency up to 40% with liquid-metal cooling. It is thought that by using magneto hydrodynamic “topping” generators in conjunction with normal steam turbines, the efficiency of conventional plants can be raised to close to 50%. These devices remove the restrictions imposed by the blade structure of turbines by using the steam or gasses produced by combustion as the working fluid.

1.6.2 Fossil fuels:

Most electricity today is generated by burning fossil fuels and producing steam which is then used to drive a steam turbine that, in turn, drives an electrical generator.
Such systems allow electricity to be generated where it is needed, since fossil fuels can readily be transported. They also take advantage of a large infrastructure designed to support consumer automobiles. The world's supply of fossil fuels is large, but finite. Exhaustion of low-cost fossil fuels

will have significant consequences for energy sources as well as for the manufacture of plastics and many other things. Various estimates have been calculated for exactly when it will be exhausted.

Fig: 1.1 An oil-fired power station in Iraq

New sources of fossil fuels keep being discovered, although the rate of discovery is slowing while the difficulty of extraction simultaneously increases.

More serious are concerns about the emissions that result from fossil fuel burning. Fossil fuels constitute a significant repository of carbon buried deep under the ground. Burning those results in the conversion of this carbon to carbon dioxide, this is then released into the atmosphere. This results in an increase in the Earth's levels of atmospheric carbon dioxide, which enhances the greenhouse effect and contributes to global warming. The linkage between increased carbon dioxide and global warming is well accepted, though fossil-fuel producers vigorously contest these findings. Depending on the particular fossil fuel and the method of burning, other emissions may be produced as well. Ozone, sulfur dioxide, NO_2 and other gases are often released, as well as particulate matter. Sulfur and nitrogen oxides contribute to smog and acid rain. In the past, plant owners addressed this problem by building very tall flue gas stacks, so that the pollutants would be diluted in the atmosphere. While this helps reduce local contamination, it does not help at all with global issues.

1.6.3 Nuclear power plant:

Nuclear power plants do not bum fossil fuels and so do not directly emit carbon dioxide; because of the high energy yield of nuclear fuels, the carbon dioxide emitted during mining, enrichment, fabrication and transport of fuel is small when compared with the carbon dioxide emitted by fossil fuels of similar energy yield. A large nuclear power plant may reject waste heat to a natural body of water; this can result in undesirable increase of the water temperature With adverse effect on aquatic life.

Fig: 1.2 Nuclear Power Plant

A plant that cools by direct use of ocean water, not requiring a cooling tower

Emission of radioactivity from a nuclear plant is controlled by regulations. Abnormal operation may result in release of radioactive material on scales ranging from minor to severe; although these scenarios are very rare. Mining of uranium ore can disrupt the environment around the mine. Disposal of spent fuel is controversial, with many proposed long-term storage schemes under intense review and criticism. Diversion of fresh or spent fuel to weapons production presents a risk of nuclear proliferation. Finally, the structure of the reactor itself becomes radioactive and will require decades of storage before it can be economically dismantled and in turn disposed of as waste.

1.6.4 Tidal power plant:

In regions such as the Bay offend with very large tidal swings, tidal power plants can be built to extract electrical power from the tidal motion.

Tidal power is also renewable, in the sense that it will continue for as long as the, Moon orbits the Earth. However, it has environmental problems similar to those of hydroelectric power. A tidal power plant usually requires a large dam, which can endanger ecosystems by restricting the motion of marine animals. Perhaps more seriously, a tidal power plant reduces or increases the tidal swing, which can severely disrupt ecosystems which depend on being periodically covered by water; resulting changes in fisheries or shellfish beds may result in adverse economic effects. Certain proposed tidal power plants in the Bay of Fund would increase the tidal swing by an estimated 50 cm as far south as the coast of Maine (where the tidal swing is not particularly large now).

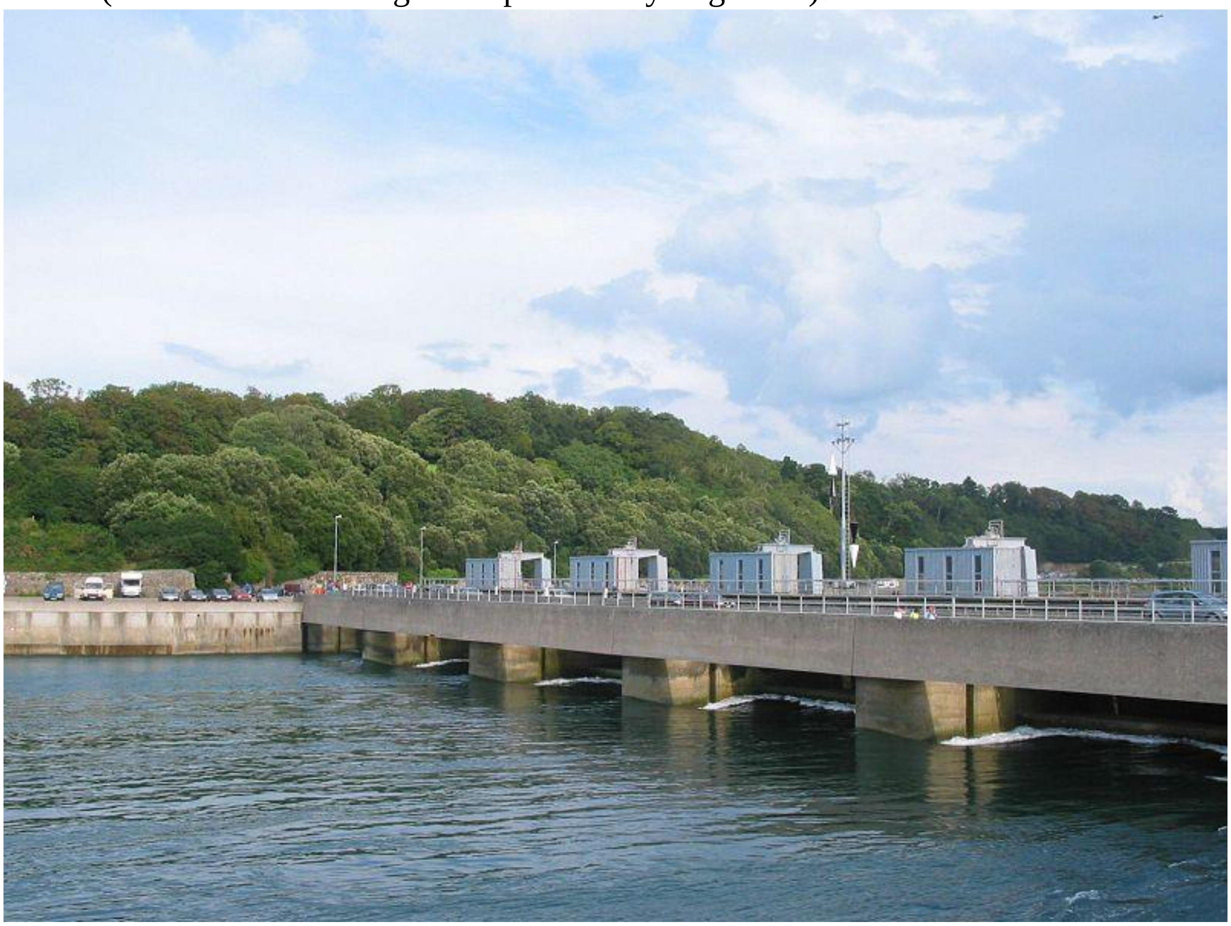


Fig:1.3 Tidal Power Plant

1.6.5 Biomass:

Electrical power can be generated by burning anything which wills combust. Some electrical power is generated by burning crops which are grown specifically for the purpose. Usually this is done by fermenting plant matter to produce ethanol, which is then burned. This may also be done by allowing organic matter to decay, producing biogas, which is then burned. Also, when burned, wood is a form of biomass fuel.

Burning biomass produces many of the same emissions as burning fossil fuels. However, growing biomass captures carbon dioxide out of the air, so that the net contribution to global atmospheric carbon dioxide levels is lessened.

The process of growing biomass is subject to the same environmental concerns as any kind of agriculture. It uses a large amount of land, and fertilizers and pesticides may be necessary for cost-effective growth. Biomass is a product of agriculture shows some promise, but most such biomass is currently being used, for plowing back into the soil as fertilizer if nothing else.

1.6.6 Wind power:

Wind power harnesses mechanical energy from the constant flow of air over the surface of the earth. Wind power stations generally consist of wind farms, fields of wind turbines in locations with relatively high winds. A primary publicity issue regarding wind turbines is their older predecessors, such as the Altamont Pass Wind Farm in California. These older, smaller, wind turbines are rather noisy and densely located, making them very unattractive to the local population. The downwind side of the turbine does disrupt local low-level winds. Modern large wind turbines have mitigated these concerns, and have become a commercially important energy source. Many homeowners in areas with high winds and expensive electricity set up small windmills to reduce their electric bills.

A modern wind farm, when installed on agricultural land, has one of the lowest environmental impacts of all energy sources: It occupies less land area per kilowatt-hour (kWh) of electricity generated than any other renewable energy conversion system, apart from rooftop solar energy, and is compatible with grazing and crops.

Fig: 1.4 Wind Turbines of 1000 kWp Capacity Wind Battery Hybrid Power Project at Kutubdia Island, Cox's Bazar District (Bay of Bengal)

1.6.6.1 Wind Power Project by Bangladesh:

1000kWp Capacity Wind Battery Hybrid Power Project at Kutubdia Island, Cox'sBazar District. Bangladesh Power Development Board (BPDB) implemented the 1000kWp capacity Wind Battery Hybrid Power Project (WBHPP) at the Kutubdia Island in the Cox’s Bazar District.

Under this project, total 50 nos. of 20kWp capacity Stand Alone Type Wind Turbines are being installed at Taboler Char areas of the Ali Akber Dell Union Parisahd of Kutubdia Upazilla. The total capacity of all the wind turbines is 1000kWp(1 MW).

The Wind turbines producing electricity which being stored in battery bank. The entire system tailed as Wind Battery Hybrid Power Plant (WBHPP). This project being installed on turn-key basis at Kutubdia, Cox's Bazar, Bangladesh.

The wind turbines produce electricity and charges the batteries at battery banks which consisting of 1000 numbers of 200AH with capacity of 12VDC. The stored electrical power from the battery banks being converted to AC (Alternative Current) by using inverters and distributed to the consumers through overhead power cable. This supply system exactly having 3-phase, On-Grid form and matches with conventional power AC system and loads.

For the conversion of the DC power from the batteries, total 8 nos. of 150KW capacity each inverter has been installed. These inverters give pure sine wave output. These 8 no's of inverters have been synchronized and paralleled. So the load out put on the system is shared by all these 8 nos. of inverters. The synchronized outputs from all these 8 nos. of inverters are put together in a common bus-bar LT pane. From the common bus-bar the totaled 3-φ out put is supplied to the LT side of a 630KVA, 0.415KV/11KV step-up transformer.

The 11KV output is taken away from the project site area to the Barghop Bazar which is about 8 km away from the project control room. This 11KV power is distributed through out the consumers of the Kutubdia Upazilla Sadar through the 11KV/0.415KV step down transformers and the distribution lines.

1.6.7 Geothermal power

Geothermal energy is the heat of the Earth, which can be tapped into to produce electricity in power plants. Warm water produced from geothermal sources can be used for industry, agriculture, bathing and cleansing. Where underground steam sources can be tapped the steam is used to run a steam turbine. Geothermal steam sources have a finite life as underground water is depleted. Arrangements that circulate surface water through rock formations to produce hot water or steam are, on a human-relevant time scale, renewable.

While a geothermal power plant does not burn any fuel, it will still have emissions due to substances other than steam which come up from the geothermal wells. These may include hydrogen sulfide, and carbon dioxide. Some geothermal steam sources entrain non-soluble minerals that must be removed from the steam before it is used for generation; this material must be properly disposed. Any (closed cycle) steam power plant requires cooling water for condensers; diversion of cooling water from natural sources, and its increased temperature when returned to streams or lakes, may have a significant impact on local ecosystems.

1.6.8 Solar power

Currently solar photovoltaic power is used primarily in Germany and Spain and in areas with an abundant amount of sun. Solar photovoltaic power works by converting the sun's radiation into DC power by use of photovoltaic cells. This power can then be converted into the more common AC power.

Solar photovoltaic power offers a viable alternative to fossils fuels for its cleanliness and supply, although at a high production cost. Future technology improvements are expected to bring this cost down to a more competitive range.
Its negative impact on the environment lies in the creation of the solar cells (which are made of primarily silicon and the extraction of this silicon requires the use of fossil fuels) and the storage of the energy (which usually requires Lead-Acid batteries). It should be noted that solar power carries an upfront cost to the environment via production, but offers clean energy throughout the lifespan of the solar cell.

Solar thermal energy is a technology that generates heat by concentrating sunlight with large mirrors and converts this heat into electricity in a classical turbine.

Chapter 2

Types of Power Plant

Introduction:

In this chapter, we shall focus on our attention on various types power plant. It can be classified in various factor as follows*(Actually we discuss about Diesel Engine power plant and Gas turbine power plant.):*

2.1.1On the basis of Fuel:

1. Steam turbine Power Plant.
2. Hydro Power Plant.
3. Diesel engine Power plant.
4. Nuclear Power Plant.
5. Gas-turbine Power Plant.
6. *VIVACE* Power plant.
7. Magneto hydrodynamic generator

2.1.2On the basis of load:

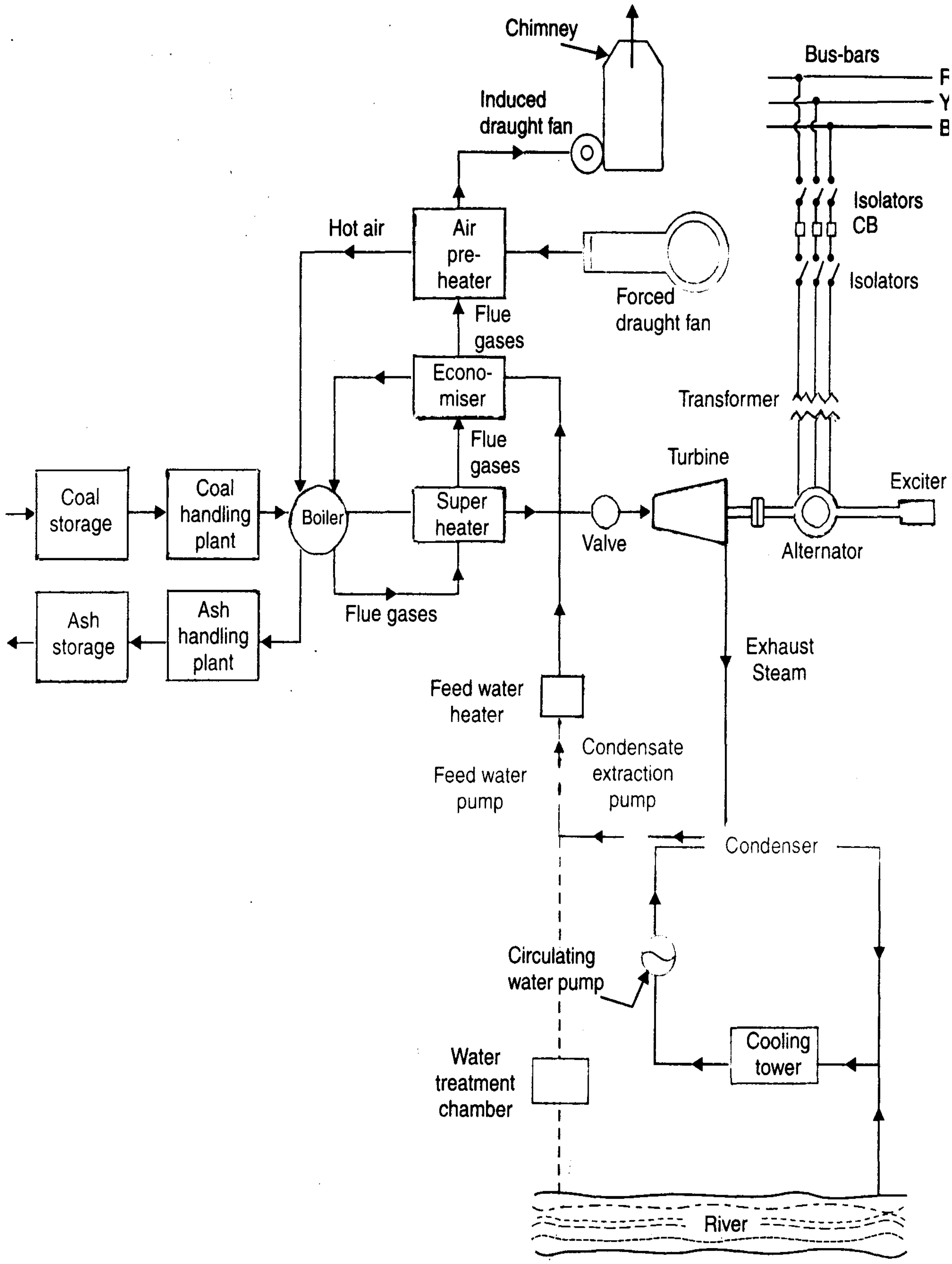
1. Peak load power plant.
2. Base load power Plant.

2.1.3On the basis of Location:

1. Isolated Power Plant.
2. Central Power Plant.

2.1.1.1 Steam turbine power Plant:

Availability of coal and water is the prerequisites to initiate this type of plant which works on the Rankine cycle. Water is heated in the boiler and steam produced, which is sent to the prime mover, i.e. turbine. The force of the steam moves the turbine and the force are directed to the alternator, which converts the mechanical forces to the electric energy.



Schematic arrangement of Steam Power Station

Figure:2.1 Steam turbine power Plant schematic arrangement

2.1.1.2 Hydro Power Plant

A generating station which utilizes the potential energy of water at a high level for the generation of electrical energy is known as a hydro electric power station.

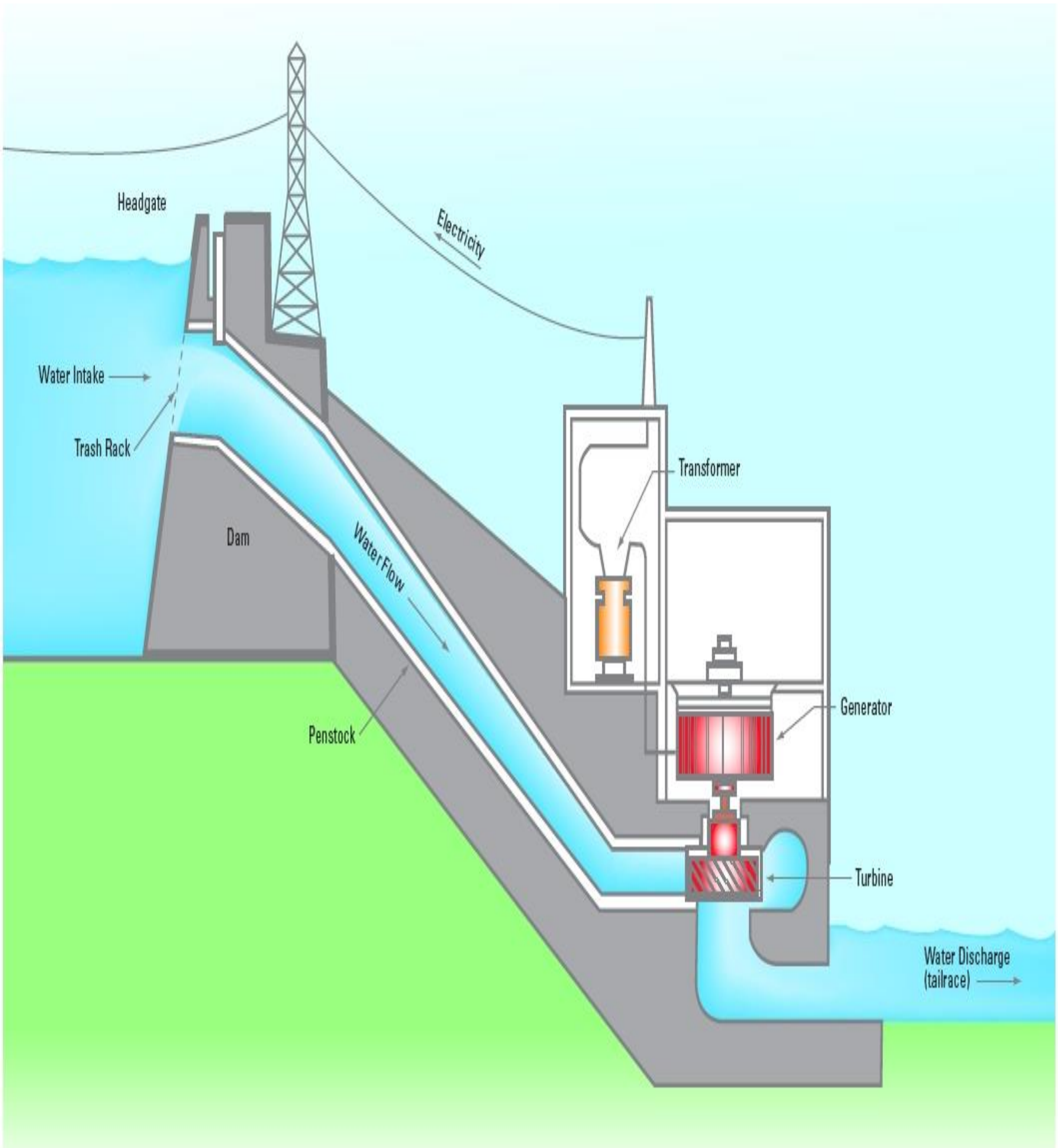


Figure: 2.2 Hydro Power Plant

2.1.1.3 Diesel engine Power plant

A generating station in which diesel engine is used as the prime mover for the generation of electrical energy is known as diesel power station.

In a diesel engine power plant the diesel burn inside the engine and products of this combustion act as a working fluid to produce mechanical energy. Diesel engine power plant is most suitable for captive generation although the generation cost is higher than gas turbine power plant. As the initial cost is reasonable in comparing with other power generating plants so the use of diesel engine is widespread and most suitable to set a captive power plant for the industries in Bangladesh.

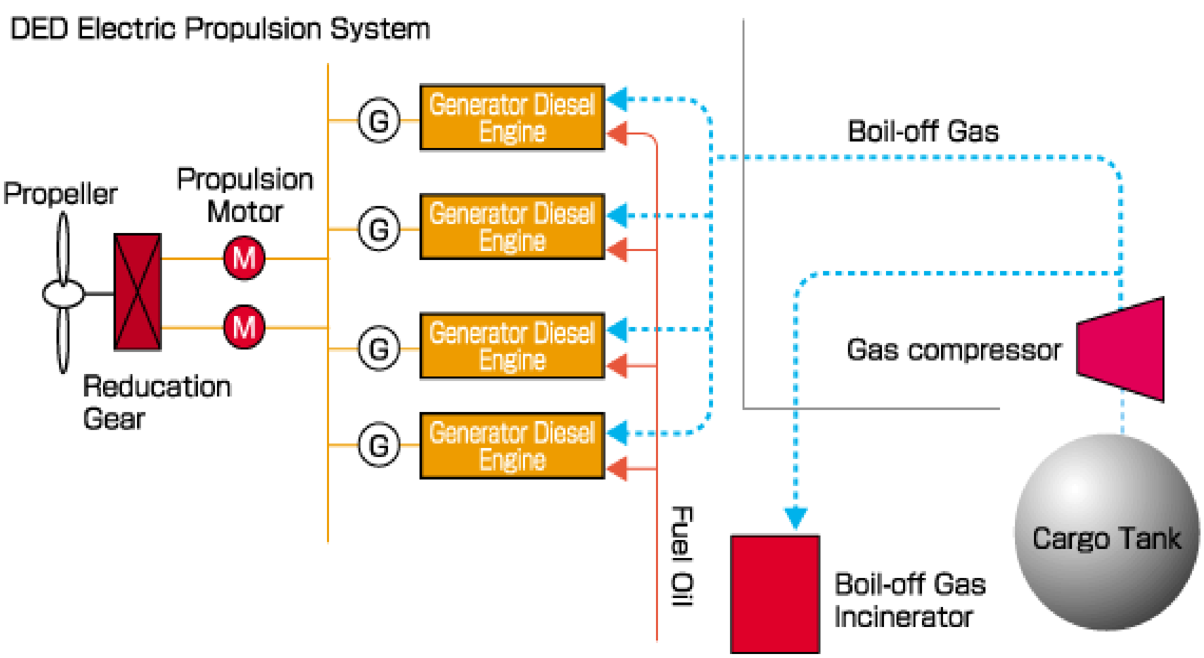


Figure:3.2 Diesel engine Power plant

2.1.1.4 Nuclear Power Plant

A generating station in which nuclear energy is converted into electrical energy is known as a nuclear power station.

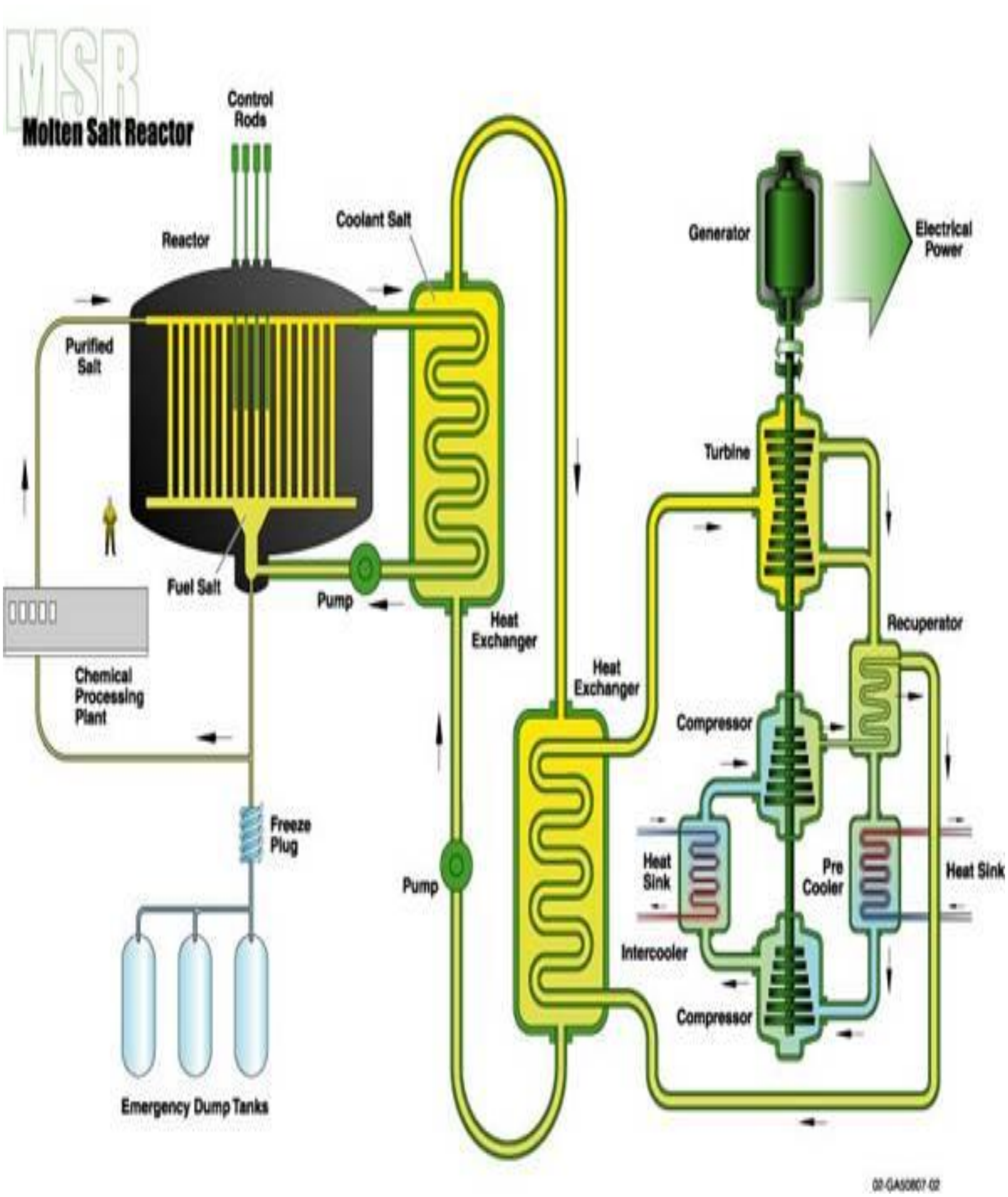
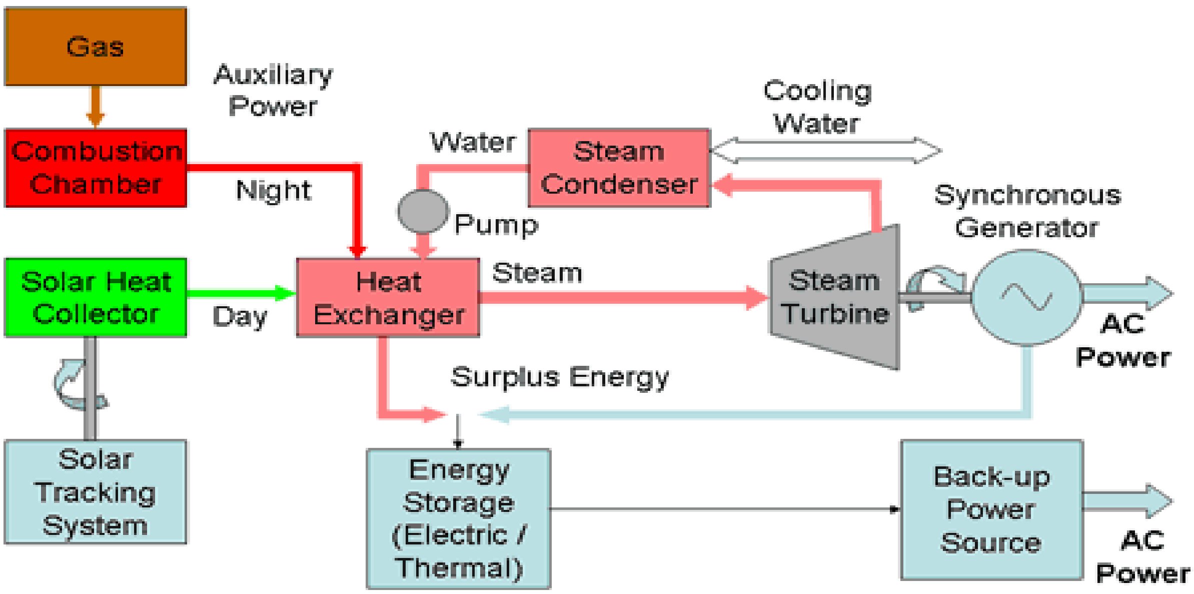


Figure: 2.4 Block diagram of Nuclear Power Plant

2.1.1.5 Solar power plant

Solar power can be converted to electricity in two ways. In one way sun light is used and directly converted to electricity which is known as the photo electric method. In other way the heat from the sun is used to boil the water which produces steam heat is converted to kinetic energy is later which converted to electricity. The station where either process or both are used to produce electricity is known as solar power plant.



Large Scale Electric Power from Solar Thermal Energy

Chapter 3

Source of power Generation in Bangladesh

Introduction:

Bangladesh is developing country. We saw how we generate Electricity using various power plants in previous Chapter .It's a not large opportunity to generated Power using all technology. Such as no much current flow of water to use Hydro power plants although Bangladesh is revering country. A nuclear power plants (3 units, each unit contain 1MW) have in Atomic Energy in Bangladesh but it is experimental. Another Nuclear power plant is proposal at Ruppur in Pabna.Its not worry to generate electricity in our Bangladesh. One windmill power plant has in Kutubdia, it perform perfectly. Bangladesh has Fossil fuel (e.g. coal, oil and natural gas) that's great opportunity to generate electricity. Now we discuss about total power generation sector in Bangladesh.

3.1 **Power Strategy in Bangladesh with captive power plant**

Electricity generation in Bangladesh is mostly natural gas based with about 85% of the existing and nearly all planned power generation plants being gas fired. Total installed capacity was 5205MW including 1320MW in and *58MW including in Rental power plants.* By types of plants 50.72% of power (MW) is produce by steam turbine (ST) plants including one coil fired power plant in Barapukuria,17.24% by gas Turbine,23.18% by combine cycle gas turbine and the rst by coal,diesel and hydro power stations. The existing fleet of ST and GT power plants operate at efficiency range of 23-34% and 18-28% respectively in sharp contrast to Combined Cycle Gas Turbine (CCGT) power plant operating at efficiency of 45-48%. However, the efficiency figures of a particular power plant largely depend on the ageing, and plant load factors and maintenance status of the respective plants.

3.2 Power Sector Structure in Bangladesh

3.2.*1* Electricity Generation various sector in Bangladesh

Peak demand is catered by*:*

Natural gas	*85%*
Liquid fuel	*6.76%*
Coal	*5.41%*
Hydropower	*2.45%*

***3.2.2 Demand from* DESA, DESC0, REB, PDB itself:**

DPDC, DESCO	*1800MW*
REB	*2200MW*
PDB itself	*1500MW*

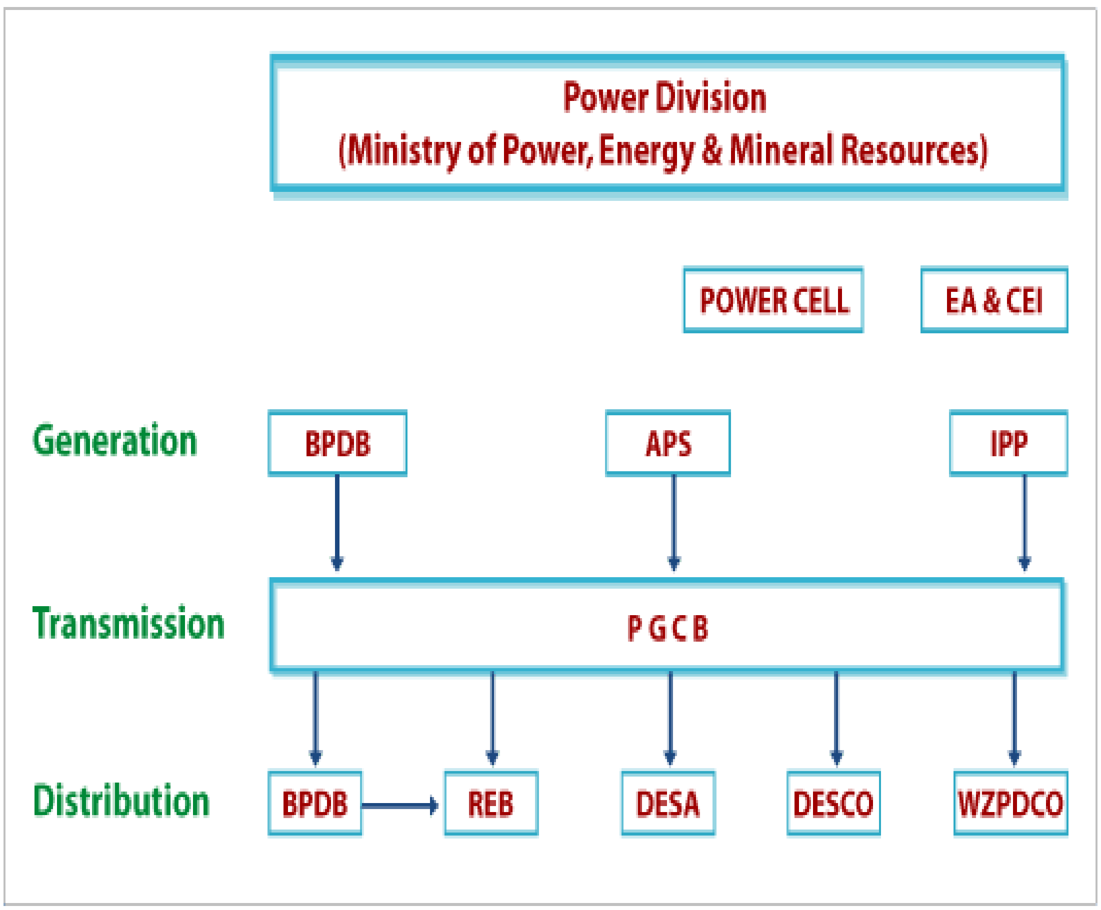


Figure :3.1 Power Sector Structure in Bangladesh

3.2.3 **Gas production capacity**

GAS PRODUCTON CAPACITY 2009			
Company	**Field**	**Producing Wells**	**Capacity (mmscfd)**
1.BGFCL	TITAS	14	405
	BAKHRABAD	4	34
	HABIGANJ	9	240
	NARSHINGDI	2	35
	MEGHNA	1	0
	Sub Total	30	714
2.SGFL	SYLHET	1	2
	KAILASHTILA	6	97
	RASHIDPUR	5	53
	BEANIBAZAR	2	18
	Sub Total	14	170
3.BAPEX	SALDANADI	2	11
	FENCHUGANJ	2	32
	Sub Total	4	43
SUBTOTAL (1+2+3)		48	927
CAIRN	SANGU	6	35
	JALALABAD	4	230
	MOULOVIBAZAR	4	75
	BIBIYANA	12	500
NIKO	FENI	3	3
TULLOW	BANGURA	2	100
Sub Total		31	943
TOTAL		**79**	**1870**

Figure:3.2 Gas Production Capacities

3.3 Power generation Data updated on November, 20, 2009

For the purpose of drawing an overall picture as to how the power plants are operating in Bangladesh in respect of fuel efficiency, and environmental aspects, the required details and information are compiled from the publicly available data with the National Load Despatch Centre, LDC Dhaka through the Power Cell website as on May 20, 2009 (Reporting date May 21, 2009). Some of the key available data as PDF file were as following

Date	November,20,2009
Day Peak generation:	3619 MW
Maximum generation:	3760.2 MW
Total Electricity generated by BPDB:)	50.04 Million kWh (MkWh
Total Electricity generated by IPP and others:	34.20 MkWh
Total Electricity generation:	84.24 MkWh
Total Gas Consumed on May 20, 2009	: 780.9 Million Cubic Feet (MMSCF)

Based on the above data, and some data taken from BPDB (Bangladesh Power Development Board) Annual Report 2007-2008, calculations are made to get a comparative overview as to how gas consumption differs among various power generation options involving Gas Turbine, Steam Turbine and Combined Cycle GT power plants. However, there could be some minor errors in the calculation as they are based on few assumptions as well, but the results of the calculation shall by and large reflect the scenario close to reality. Table below depicts a picture in this respect.

Type of plants	Electricity Generated, Million kWh	Gas Burnt, Million SCF on May 20, 2009	Gas Burnt to produce one kWh of electricity, SCF/kWh	Excess Gas Burnt*, Million SCF on May 20, 2009	Excess Gas to be Consumed* in 25 Years, Trillion Cubic Feet
Stem Turbine	36.76	398.4	10.83	112	.901
Gas Turbine	9.23	114.5	12.37	42	.340
Combined Cycle	23.72	184.0	7.78	-	-
Gas Engines	8.35	84.0	10.03	19	.151
Total		780.9	---	173	1.582

Table 1: Gas Consumption Scenario in Power Plants on November 20, 2009

*{*Excess Gas burnt means the gas burnt by Steam Turbine, Gas Turbine and Gas Engines in excess of what is required by a Combined Cycle power plant to produce an equal amount of electricity. For example, to produce electricity of 9.23 MkWh, the GT burns about 42 MSCF of excess gas compared to what the combined cycle power would burn to produce same amount of electricity, and so is the cost.}*

Chapter 4

Choice of Captive Power Plant in Bangladesh

Introduction

Captive power plant is a plant for creating electricity to the needs of a particular Industry or a group for their own use & the installed capacity shall not exceed50MW. Industrial sector is one of the largest consumers of electrical energy in Bangladesh. However, a number of industries are now increasingly relying on their own generation (Captive & cogeneration) rather than on grid supply, primarily for the following reasons:
a) Non-availability of adequate grid supply &

b) Poor quality & reliability of grid supply, high tariff as a result of heavy Cross-subsidization. As a result, of the captive cogeneration potential has been increasing over the Years & it is estimated that nearly 30 percent of the requirements of the industrial Sector is met from in-house generation. Some of the recently published statistics indicate a captive power potential to the tune of 1300MW. Looking at the trends in Generation capacity additions in the public & private sector, the role & significance of Captive & cogeneration are expected to increase in coming years. The government & Power Development Board (PDB) are aware of their inability to meet the needs of the power of the industries. In the immediate future various policy Initiatives have also been taken to promote captive power production & cogeneration. The captive power producers & cogeneration promoters by & large do not appear to be happy with the present policy initiatives & have been asking for increased Incentives. The government has been cautious in their response for reasons stated above. The Bangladesh Energy Regulatory Commission (BERC) will now be concerned with the approval for setting power plants & third party sales.

4.1 Fiscal Incentives:

1) Separate billing can be carried out for Export & Import of energy by the Captive Power Plants.
2) The period of supply of power of Captive Power Plant to a utility shall normally be during the peak hour.
3) Unless otherwise decided, there will be no fiscal incentives & benefits for setting up power plants under this policy.
4) Each CPP will be able to sell electricity to eligible & consumers on bilaterally Agreed terms provided that it enters into wheeling agreement with the host Distribution licensee, to any other distribution licensee at published purchase tariffs.
5) Each CPP will be able to sell electricity to eligible end consumers on bilaterally agreed terms provided that it enters into a wheeling agreement with relevant Distribution and/or transmission licensees.

4.2 Captive Power Generation in Bangladesh

Installation of new unit in the existing new captive power plants is likely to offer relief as the government is struggling to augment electricity supply within a shortest possible time. The government might get electricity of up to 1100MW, of which 300MW will be added before the next summer & 800MW by the next one year, from the captive plants if new power units are installed there. The captive power owners will be able to provide electricity at the earliest as the necessary infrastructure like land & gas connections are already there. But the irrational tariff offer coupled with higher gas prices is hindering the government plan to augment the country's electricity generation through purchase of electricity from the captive power plant. Currently, the Bangladesh Power Development Board (BPDB) & the Independent Power Producers (IPPs) are purchasing gas at Taka 2.61 per cubic meter, which the gas rate for the captive power plants is Taka 3.73 per cubic meter. Failing to entice the CPP owners to sell electricity at the current rate of Taka 2.12 per kilowatt hour (per unit) the Power Division, however, recently placed a proposal to the Council of Advisers for revising the existing Captive Power Policy (CPP) with an enhancement of electricity tariff by a maximum of five percent as compensation for the cost involved in transmitting electricity into the national grid. The Power Division wants the generators to be installed by the captive plants should be of special design. But the proposed hike in tariff structure for the captive power plants is inadequate compared to the transmission cost of electricity from captive plants to national grid is around Taka 25 million for generation of 1.0MW power. Initially, power division hoped that the captive power plant owners would provide their 'surplus' electricity. The existing gas tariff structure for the captive power plants is discouraging to provide electricity to the national grid. Currently, the Bangladesh Power Development Board (BPDB) 7^{th} Independent Power Producers (IPPs) are purchasing gas at Taka 2.61 per cubic meter, which is Taka 1.12 less than the purchasing rate of the captive power. The captive power plants are purchasing gas at Taka 3.73 per cubic meter from government. The total generation of power units is currently over 1300MW across the country.

4.3 Diesel power plant

Diesel engine is the prime mover, which drives an alternator to produce electrical energy. In the diesel engine, air is drawn into the cylinder and is compressed to a high ratio (14:1 to 25:1). During this compression, the air is heated to a temperature of 700–9000C. A metered quantity of diesel fuel is then injected into the cylinder, which ignites spontaneously because of the high temperature. Hence, the diesel engine is also known as compression ignition (CI) engine.

DG set can be classified according to cycle type as: two stroke and four stroke. However, the bulk of IC engines use the four stroke cycle. Let us look at the principle of operation of the four-stroke diesel engine.

Four Strokes - Diesel Engine:

The 4 stroke operations in a diesel engine are: induction stroke, compression stroke, ignition and power stroke and exhaust stroke.

1st: Induction stroke - while the inlet valve is open, the descending piston draws in fresh air.

2nd: Compression stroke - while the valves are closed, the air is compressed to a pressure of up to 25 bar.

3rd: Ignition and power stroke - fuel is injected, while the valves are closed (fuel injection actually starts at the end of the previous stroke), the fuel ignites spontaneously and the piston is forced downwards by the combustion gases.

4th: Exhaust stroke - the exhaust valve is open and the rising piston discharges the spent gases from the cylinder.

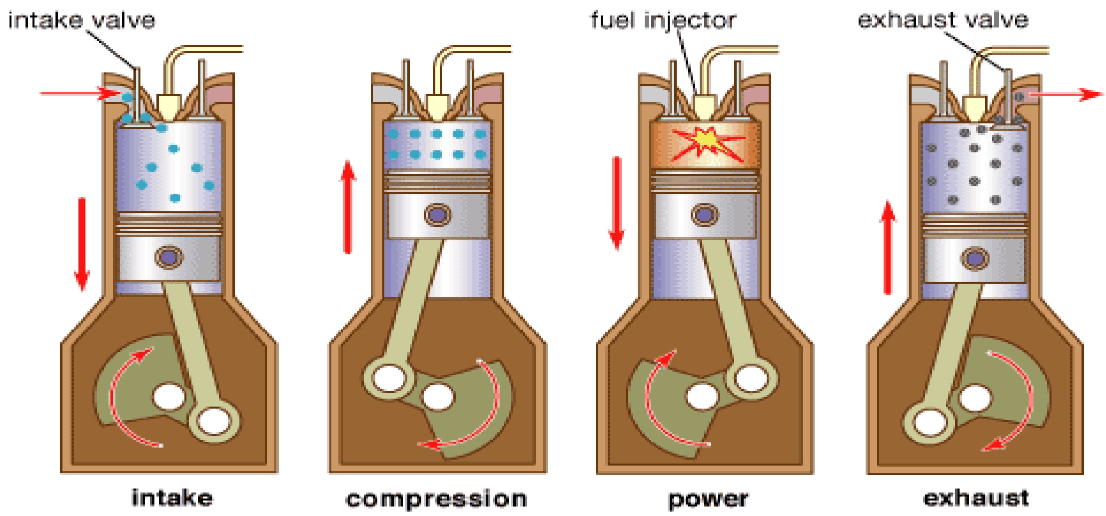


Figure: 4.1 Diesel engine stroke

Since power is developed during only one stroke, the single cylinder four-stroke engine has a low degree of uniformity. Smoother running is obtained with multi cylinder engines because the cranks are staggered in relation to one another on the crankshaft. There are many variations of engine configuration, for example. 4 or 6 cylinder, in-line, horizontally opposed, vee or radial configurations.

DG Set as a System:

A diesel generating set should be considered as a system since its successful operation depends on the well-matched performance of the components, namely:

a) The diesel engine and its accessories.

b) The AC Generator.

c) The control systems and switchgear.

d) The foundation and power house civil works.

e) The connected load with its own components like heating, motor drives, lighting etc.

It is necessary to select the components with highest efficiency and operate them at their optimum efficiency levels to conserve energy in this system.

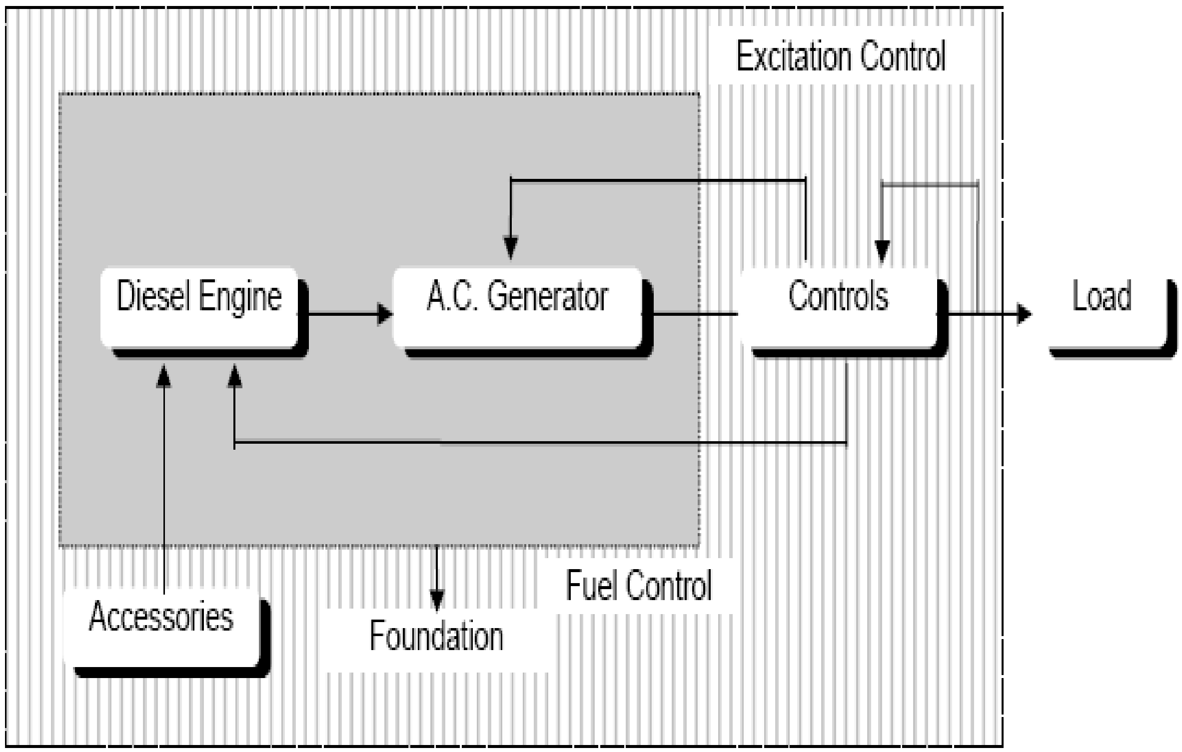


Figure: 4.2 DG Set System

Selection Considerations

To make a decision on the type of engine, which is most suitable for a specific application, several factors need to be considered. The two most important factors are: power and speed of the engine.

The power requirement is determined by the maximum load. The engine power rating should be 10-20 % more than the power demand by the end use. This prevents overloading the machine by absorbing extra load during starting of motors or switching of some types of lighting systems or when wear and tear on the equipment pushes up its power consumption.

Speed is measured at the output shaft and given in revolutions per minute (RPM). An engine will operate over a range of speeds, with diesel engines typically running at lower speeds (1300 - 3000 RPM). There will be an optimum speed at which fuel efficiency will be greatest. Engines should be run as closely as possible to their rated speed to avoid poor efficiency and to prevent build up of engine deposits due to incomplete combustion - which will lead to higher maintenance and running costs. To determine the speed requirement of an engine, one has to again look at the requirement of the load.

For some applications, the speed of the engine is not critical, but for other applications such as a generator, it is important to get a good speed match. If a good match can be obtained, direct coupling of engine and generator is possible; if not, then some form of gearing will be necessary - a gearbox or belt system, which will add to the cost and reduce the efficiency.

There are various other factors that have to be considered, when choosing an engine for a given application. These include the following: cooling system, abnormal environmental conditions (dust, dirt, etc.), fuel quality,

speed governing (fixed or variable speed), poor maintenance, control system, starting equipment, drive type, ambient temperature, altitude, humidity, etc.
Suppliers or manufacturers literature will specify the required information when purchasing an engine. The efficiency of an engine depends on various factors, for example, load factor (percentage of full load), engine size, and engine type.

4.3.1 Advantage of Diesel Power plant

Advantages of diesel engine station rather others Power Station for Captive power generation

1. Diesel Engine power plant is small size that is great advantage of industries.
2. It is quite neat clean.
3. A diesel engine station can be started and stopped quickly.
4. There is no thus stand by losses.
5. In diesel engine power plant does not need a large amount of water for cooling system.
6. It works peak load as instant.
7. The reserve capacity for a diesel plant used in this way depends on the processes in the particular industries that is whether it is absolutely necessary to maintain constant frequency where a slight venation would be acceptable whether continuity and reliability of supply is essential for all 24 hours of the day or whether some interruption is permissible.
8. There is no need to reserve plant so that the cost of power produced is loner
9. Most of all the tactic change is cheaper instead other power plant and rather than buying power from utility companies or a Gird system.
10. It required to short time to dowsing.

4.3.2 Disadvantage of Diesel Power Plant

Disadvantage of diesel power station:

- The plant had high running charges as the fuel (i.c diesel) used is costly.
- The plant does not work satisfactorily under overload conditions for longer period.
- The plant can only generate small power.
- The cost of lubrication is generally high.
- The maintenance charges are generally high.

4.4 Diesel Engine Vs Gas Engine power plant

In the above discussion it's cleared that Gas engine Power plant is better then Diesel Engine power Plant for Captive power generation. The main reason to choose gas engine is per unit cost. But commercially other facts are also considered, for example initial cost plays a greater role in setting a captive power plant. It takes two to three times more investment in setting a gas engine power plant than a diesel engine power plant. High maintenance cost of Gas engine is another important reason to choose diesel engine as the maintenance cost of diesel engine is relatively lower than that of gas engine. Again in some places still the supply of gas is not established and/or sometimes the pressure of gas is too low to run a gas engine properly, where proper supply of diesel is a problem seldom.

4.5 Mathematical Analysis to choice Gas or Diesel:

Cost estimation of 780KVA (Prime) standby and when it operate base load then it capacity is 700KVA.

Real power P=780KVA× 0.8= 624 KW

For the maximum o/p at 75%of 624KW = 468KW

1. Cost of fuel
2. Lubrication Oil
3. Coolant
4. Filtration system
5. Maintenance cost

DIESEL

To produce 468KW per hr need total diesel =115Lt
Let, per unit Diesel= 44.00Tk
=Total litters× Unit liter cost
Per hour Fuel cost=115 × 44
= 5060Tk
= Total Cane × per cane contain 5Lts
=25 × 5Lt
Total Lubrication oil = 125 Lt
Total cost= 25×1250
(Total cane *per cane cost)
=31250/200hrs (*It's required a Time interval normally its 200 hrs*)
Per hr Lubrication cost=156Tk/hr
=40 × 1000
= 40000/400hrs (*It's required a Time interval normally its 400 hrs*)
Per hr Coolant cost=100Tk
=30000/200hrs
Per hr Filtration cost= 150Tk
=50000/400hrs (*It's required a Time interval normally its 400 hrs*)
Per hr Maintenance cost=125Tk

GAS

To produce 468KW/hr need total Gas =160 m^3
Let Per m^3 Gas=6Tk.
= Total m^3 /hr × per m^3 cost
Per hour Fuel cost =160 ×6 = 960Tk

Per hr Lubrication oil = 160Tk

Per hr Coolant cost = 120Tk

Per hr Filtration cost = 180Tk

Per hr Maintenance cost =180Tk

Per Unit Calculation Diesel and Gas Engine

DIESEL

Per hour Fuel cost=115 × 44 = 5060Tk

Per hr Lubrication cost = 156Tk

Per hr Coolant cost = 100Tk

Per hr Filtration cost = 150Tk

Per hr Maintenance cost = 125Tk

= 5591Tk.

Now cost KW/hr = $\frac{Total'Cost}{Total'Output}$

$= \frac{5591'Tk}{468\,\frac{KW}{hr}}$

= 11.94 Tk/Unit

Gas

Per hour Fuel cost =160 ×6 = 960Tk

Per hr Lubrication oil = 160Tk

Per hr Coolant cost =120Tk

Per hr Filtration cost = 180Tk

Per hr Maintenance cost =180Tk

=1600Tk

Now cost KW/hr = $\frac{Total'Cost}{Total'Output}$

$= \frac{1600'Tk}{468\,\frac{KW}{hr}}$

= 3.41 Tk/Unit

Chapter 5

Control of Engine

Introduction:

An engine control unit (ECU), also known as power-train control module (PCM), or engine control module (ECM) is a type of electronic control unit that determines the amount of fuel, ignition timing and other parameters an internal combustion engine needs to keep running. It does this by reading values from multidimensional maps which contain values calculated by sensor devices monitoring the engine.
Before ECU's, fuel injection, ignition timing, and idle speed were directly controlled by mechanical and pneumatic sensors and actuators.

5.1 Control of fuel injection

For an engine with fuel injection, an ECU or engine control unit, will determine the quantity of fuel to inject based on a number of parameters. If the throttle pedal is pressed further down, this will open the throttle body and allow more air to be pulled into the engine. The ECU will inject more fuel according to how much air is passing into the engine. If the engine has not warmed up yet, more fuel will be injected (causing the engine to run slightly 'rich' until the engine warms up).'

5.2 Control of ignition timing

A spark ignition engine requires a spark to initiate combustion in the combustion chamber. An ECU can adjust the exact timing of the spark (called ignition timing) to provide better power and economy. If the ECU detects knock, a condition which is potentially destructive to engines, and "judges" it to be the result of the ignition timing being too early in the compression stroke, it will delay (retard) the timing of the spark to prevent this.
A second, more common source, cause, of knock/ping is operating the engine in too low of an RPM range for the "work" requirement of the moment. In this case the knock/ping results from the piston not being able to move downward as fast as the flame front is expanding, but this latter mostly applies only to manual transmission equipped vehicles. The ECU controlling an automatic transmission would simply downshift the transmission if this were the cause of knock/ping.

5.3 Control of idle speed

Most engine systems have idle speed control built into the ECU. The engine RPM is monitored by the crankshaft position sensor which plays a primary role in the engine timing functions for fuel injection, spark events, and valve timing. Idle speed is controlled by a programmable throttle stop or an idle air bypass control stepper motor. Early carburetor based systems used a programmable throttle stop using a bidirectional DC motor. Early TBI systems used an idle air control stepper motor. Effective idle speed control must anticipate the engine load at idle. Changes in this idle load may come from HVAC systems, power steering systems, power brake systems, and electrical charging and supply systems. Engine temperature and transmission status, and lift and duration of camshaft also may change the engine load and/or the idle speed value desired.

A full authority throttle control system may be used to control idle speed, provide cruise control functions and top speed limitation.

5.4 **Control of variable valve timing**

Some engines have Variable Valve Timing. In such an engine, the ECU controls the time in the engine cycle at which the valves open. The valves are usually opened sooner at higher speed than at lower speed. This can optimize the flow of air into the cylinder, increasing power and economy.

5.5 **Electronic valve control**

Experimental engines have been made and tested that have no camshaft, but has full electronic control of the intake and exhaust valve opening, valve closing and area of the valve opening.[1] Such engines can be started and run without a starter motor for certain multi-cylinder engines equipped with precision timed electronic ignition and fuel injection. Such a static-start engine would provide the efficiency and pollution-reduction improvements of a mild hybrid-electric drive, but without the expense and complexity of an oversized starter motor.[2]

5.**6 Programmable ECUs**

A special category of ECUs are those which are programmable. These units do not have a fixed behavior, but can be reprogrammed by the user.

Programmable ECUs are required where significant aftermarket modifications have been made to a vehicle's engine. Examples include adding or changing of a turbocharger, adding or changing of an intercooler, changing of the exhaust system, and conversion to run on alternative fuel. As a consequence of these changes, the old ECU may not provide appropriate control for the new configuration. In these situations, a programmable ECU can be wired in. These can be programmed/mapped with a laptop connected using a serial or USB cable, while the engine is running.The programmable ECU may control the amount of fuel to be injected into each cylinder. This varies depending on the engine's RPM and the position of the gas pedal (or the manifold air pressure). The engine tuner can adjust this by bringing up a spreadsheet-like page on the laptop where each cell represents an intersection between a specific RPM value and a gas pedal position (or the throttle position, as it is called). In this cell a number corresponding to the amount of fuel to be injected is entered. This spreadsheet is often referred to as a fuel table or fuel map.

By modifying these values while monitoring the exhausts using a wide band lambda probe to see if the engine runs rich or lean, the tuner can find the optimal amount of fuel to inject to the engine at every different combination of RPM and throttle position. This process is often carried out at a dynamometer, giving the tuner a controlled environment to work in. An engine dynamometer gives a more precise calibration for racing applications. Tuners often utilize a chassis dynamometer for street and other high performance applications.

5.7 **Other parameters that are often map able are**:

* Ignition: Defines when the spark plug should fire for a cylinder.

* Rev. limit: Defines the maximum RPM that the engine is allowed to reach. After this fuel and/or ignition is cut. Some vehicle have a "soft" cut-off before the "hard" cut-off.

* Water temperature correction: Allows for additional fuel to be added when the engine is cold (choke) or dangerously hot.

* Transient fueling: Tells the ECU to add a specific amount of fuel when throttle is applied. The term is "acceleration enrichment"

* Low fuel pressure modifier: Tells the ECU to increase the injector fire time to compensate for a loss of fuel pressure.

* Closed loop lambda: Lets the ECU monitor a permanently installed lambda probe and modify the fueling to achieve stoichiometric (ideal) combustion. On traditional petrol powered vehicles this air:fuel ratio is 14.7:1.
Some of the more advanced race ECUs include functionality such as launch control, limiting the power of the engine in first gear to avoid burnouts. Other examples of advanced functions are:

* Wastegate control: Sets up the behavior of a turbocharger's wastegate, controlling boost.

* Banked injection: Sets up the behavior of double injectors per cylinder, used to get a finer fuel injection control and atomization over a wide RPM range.

* Variable cam timing: Tells the ECU how to control variable intake and exhaust cams.

* Gear control: Tells the ECU to cut ignition during (sequential gearbox) upshifts or blip the throttle during downshifts.

A race ECU is often equipped with a data logger recording all sensors for later analysis using special software in a PC. This can be useful to track down engine stalls, misfires or other undesired behaviors during a race by downloading the log data and looking for anomalies after the event. The data logger usually has a capacity between 0.5 and 16 megabytes.

In order to communicate with the driver, a race ECU can often be connected to a "data stack", which is a simple dash board presenting the driver with the current RPM, speed and other basic engine data. These race stacks, which are almost always digital, talk to the ECU using one of several proprietary protocols running over RS232 or CAN bus, connecting to the DLC connector (Data Link Connector) usually located on the underside of the dash, in line with the steering wheel.

5.8 **ECU flashing**

Many recent (around 1996 or newer) cars use OBD-II ECUs that are sometimes capable of having their programming changed through the OBD port. Automotive enthusiasts with modern cars take advantage of this technology when tuning their engines. Rather than use an entire new engine management system, one can use the appropriate software to adjust the factory equipped computer. By doing so, it is possible to retain all stock functions and wiring while using a custom tuned program. This should not be confused with "chip tuning", where the owner has ECU ROM physically replaced with a different one—no hardware modification is (usually) involved with flashing ECUs, although special equipment is required.
Factory engine management systems often have similar controls as aftermarket units intended for racing, such as 3-dimensional timing and fuel control maps. They generally do not have the ability to control extra ancillary devices, such as variable valve timing if the factory vehicle was a fixed geometry camshaft or boost control if the factory car was not turbocharged.

5.9 **Hybrid digital designs**

Hybrid digital/analog designs were popular in the mid 1980s. This used analog techniques to measure and process input parameters from the engine, then used a look-up table stored in a digital ROM chip to yield pre computed output values. Later systems compute these outputs dynamically. The ROM type of system is amenable to tuning if one knows the system well. The disadvantage of such systems is that the pre computed values are only optimal for an idealized, new engine. As the engine wears, the system is less able to compensate than a CPU based system.

5.10 **Modern ECUs**

Modern ECUs use a microprocessor which can process the inputs from the engine sensors in real time. An electronic control unit contains the hardware and software (firmware). The hardware consists of electronic components on a printed circuit board (PCB), ceramic substrate or a thin laminate substrate. The main component on this circuit board is a microcontroller chip (CPU). The software is stored in the microcontroller or other chips on the PCB, typically in EPROMs or flash memory so the CPU can be re-programmed by uploading updated code or replacing chips. This is also referred to as an (electronic) Engine Management System (EMS).

Sophisticated engine management systems receive inputs from other sources, and control other parts of the engine; for instance, some variable valve timing systems are electronically controlled, and turbocharger waste gates can also be managed. They also may communicate with transmission control units or directly interface electronically-controlled automatic transmissions, traction control systems, and the like. The Controller Area Network or CAN bus automotive network is often used to achieve communication between these devices.

Modern ECUs sometimes include features such as cruise control, transmission control, anti-skid brake control, and anti-theft control, etc.

General Motors' first ECUs had a small application of hybrid digital ECUs as a pilot program in 1979, but by 1980, all active programs were using microprocessor based systems. Due to the large ramp up of volume of ECUs that were produced to meet the US Clean Air Act requirements for 1981, only one ECU model could be built for the 1981 model year.[3] The high volume ECU that was installed in GM vehicles from the first high volume year, 1981, onward was a modern microprocessor based system. GM moved rapidly to replace carburetor based systems to fuel injection type systems starting in 1980/1981 Cadillac engines, following in 1982 with the Pontiac 2.5L "GM Iron Duke engine" and the Corvette Chevrolet L83 "Cross-Fire" engine. In just a few years all GM carburetor based engines had been replaced by throttle body injection (TBI) or intake manifold injection systems of various types. In 1988 Delco Electronics, Subsidiary of GM Hughes Electronics, produced more than 28,000 ECUs per day, the world's largest producer of on-board digital control computers at the time.[4]

5.11 **Other applications**

Such systems are used for many internal combustion engines in other applications. In aeronautical applications, the systems are known as "FADECs" (Full Authority Digital Engine Controls). This kind of electronic control is less common in piston-engined aeroplanes than in automobiles, because of the large costs of certifying parts for aviation use, relatively small demand, and the consequent stagnation of technological innovation in this market.[citation needed] Also, a carburated engine with magneto ignition and a gravity feed fuel system does not require electrical power generated by an alternator to run, which is considered a safety advantage.[5]

An air flow meter, commonly abbreviated to AFM, also known as an air consumption meter is a device that measures how much air is flowing through a tube. It does not measure the volume of the air passing through the tube, it measures the actual speed of the air flowing through the device in a defined time segment. Thus air flow meters aresimply an application of mass flow meters for a special medium. Typically, mass air flow measurements are expressed in the units of kilograms per hour (kg/h).

5.12 **Air-fuel ratio meter**

An air-fuel ratio meter monitors the air-fuel ratio of an internal combustion engine. Also called air-fuel ratio gauge, air-fuel meter, or air-fuel gauge. It reads the voltage output of an oxygen sensor, sometimes also called lambda sensor, whether it be from a narrow band or wide band oxygen sensor.

The original narrow band oxygen sensors became factory installed standard in the late 70's and early 80's. In recent years, a newer and much more accurate 'wide band' sensor, though more expensive, has become available.

Most stand-alone narrow band meters have 10 LEDs and some have more. Also common, narrow band meters in round housings with the standard mounting 2 1/16" and 2 5/8" diameters, as other types of car 'gauges'. These usually have 10 or 20 LEDs. Analogue 'needle' style gauges are also available.

As stated above, there are wide band meters that stand alone or are mounted in housings. Nearly all of these show the air-fuel ratio on a numeric display, since the wide band sensors provide a much more accurate reading. And since they use more accurate electronics, these meters are more expensive

5.12.1 Benefits of air-fuel ratio metering

* Determining the condition of the oxygen sensor: A malfunctioning oxygen sensor will result in air-fuel ratios which respond more slowly to changing engine conditions. A damaged or defective sensor may lead to increased fuel consumption and increased pollutant emissions as well as decreased power, and throttle response.

* Reducing emissions: Keeping the air-fuel mixture near the stoichometric ratio of 14.7:1 (for gasoline engines) allows the catalytic converter to operate at maximum efficiency.

* Fuel economy: An air-fuel mixture leaner than the stoichometric ratio will result in near optimum fuel mileage, costing less per mile traveled and producing the least amount of CO_2 emissions. However, from the factory, cars are designed to operate at the stoichometric ratio (rather than as lean as possible while remaining driveable) in order to maximize the efficiency and life of the catalytic converter. While it may be possible to run smoothly at mixtures leaner than the stoichimetric ratio, manufacturers must focus on emissions and especially catalytic converter life (which must now be 100,000 miles on new vehicles[citation needed]) as a higher priority due to U.S. EPA regulations.

* Engine performance: Carefully mapping out air-fuel ratios throughout the range of rpm and manifold pressure will maximize power output in addition to reducing the risk of detonation.

Lean mixtures improve the fuel economy but also cause sharp rises in the amount of nitrogen oxides (NOX). If the mixture becomes too lean, the engine may fail to ignite, causing misfire and a large increase in unburned hydrocarbon (HC) emissions. Lean mixtures burn hotter and may cause rough idle, hard starting and stalling, and can even damage the catalytic converter, or burn valves in the engine. The risk of spark knock/engine knocking (detonation) is also increased when the engine is under load.

Mixtures that are richer than stoichometric allow for greater peak engine power when using gaseous fuels, due to the cooling effect of the evaporating fuel. This increases the intake oxygen density, allowing for more fuel to be combusted and more power developed. The ideal mixture in this type of operation depends on the individual engine. For example, engines with forced induction such as turbochargers and superchargers typically require a richer mixture under wide open throttle than naturally aspirated engines. Forced induction engines can be catastrophically damaged by burning too lean for too long. The leaner the air/fuel mixture, the higher the combustion temperature is inside the cylinder. Too high a temperature will destroy an engine - melting the pistons and valves. This can happen if you port the head and/or manifolds or increase boost without compensating by installing larger or more injectors, and/or increasing the fuel pressure to a sufficient level. Conversely, engine performance can be lessened by increasing fuelling without increasing air flow into the engine.

Cold engines also typically require more fuel and a richer mixture when first started (see: cold start injector), because fuel does not vaporize as well when cold and therefore requires more fuel to properly "saturate" the air. Rich mixtures also burn slower and decrease the risk of spark knock/engine knocking (detonation) when the engine is under load. However, rich mixtures sharply increase carbon monoxide (CO) emissions.

5.12.2 Oxygen sensor types

Oxygen sensors are installed in the exhaust system of the vehicle, attached to the engine's exhaust manifold, the sensor measures the ratio of the air-fuel mixture.
As mentioned above, there are two types of sensors available; narrow band and wide band. Narrow band sensors were the first to be introduced. The wide band sensor was introduced much later.
A narrow band sensor has a non-linear output, and switches between the thresholds of lean (ca 100-200 mV) and rich (ca 650-800 mV) areas very steeply.
Also, narrow band sensors are temperature-dependent. If the exhaust gases become warmer, the output voltage in the lean area will rise, and in the rich area it will be lowered. Consequently, a sensor, without pre-heating has a lower lean-output and a higher rich-output, possibly even exceeding 1 Volt. The influence of temperature to voltage is smaller in the lean mode than in the rich mode.A "cold" engine makes the sensor switch the output voltage between ca 100 and 850/900 mV and after a while the sensor may output a switch voltage between ca 200 and 700/750mV, for turbocharged cars even less.
The Engine Control Unit (ECU) tries to maintain a stoichiometric balance, wherein the air-fuel mixture is approximately 14.7 times the mass of air to fuel for gasoline. This ratio is selected in order to maintain a neutral engine performance (lower fuel consumption yet decent engine power and minimal pollution).
The average level of the sensor is defined as 450 mV. Since narrow band sensors cannot output a fixed voltage level between the lean and the rich areas, the ECU tries to control the engine by controlling the mixture between lean and rich in such a sufficiently fast manner, that the average level becomes ca 450 mV.
A wide band sensor, on the other hand, has a very linear output, 0 - 5 V, and is not temperature dependent.

5.12.3**Which type of air-fuel ratio meter to be used**

If the purpose of the air-fuel ratio meter is to diagnose an existing or possible problem with the sensor and/or to check the general mixture and performance, a narrow band air-fuel ratio meter is sufficient.
In high-performance tuning applications the wide-band system is desirable.

Fuel injection is a system for mixing fuel with air in an internal combustion engine. It has become the primary fuel delivery system used in automotive petrol engines, having almost completely replaced carburetors in the late 1980s.

A fuel injection system is designed and calibrated specifically for the type(s) of fuel it will handle. Most fuel injection systems are for gasoline or diesel applications. With the advent of electronic fuel injection (EFI), the diesel and gasoline hardware has become similar. EFI's programmable firmware has permitted common hardware to be used with different fuels.

Carburetors were the predominant method used to meter fuel on gasoline engines before the widespread use of fuel injection. A variety of injection systems have existed since the earliest usage of the internal combustion engine.

The primary difference between carburetors and fuel injection is that fuel injection atomizes the fuel by forcibly pumping it through a small nozzle under high pressure, while a carburetor relies on low pressure created by intake air rushing through it to add the fuel to the airstream.

The fuel injector is only a nozzle and a valve: the power to inject the fuel comes from a pump or a pressure container farther back in the fuel supply.

5.12.4 **Objectives**

The functional objectives for fuel injection systems can vary. All share the central task of supplying fuel to the combustion process, but it is a design decision how a particular system will be optimized. There are several competing objectives such as:

* power output
* fuel efficiency
* emissions performance
* ability to accommodate alternative fuels
* reliability
* driveability and smooth operation
* initial cost
* maintenance cost
* diagnostic capability
* range of environmental operation

Certain combinations of these goals are conflicting, and it is impractical for a single engine control system to fully optimize all criteria simultaneously. In practice, automotive engineers strive to best satisfy a customer's needs competitively. The modern digital electronic fuel injection system is far more capable at optimizing these competing objectives consistently than a carburetor. Carburetors have the potential to atomize fuel better (see Pogue and Allen Caggiano patents).

5.13 **Engine operation**

Operational benefits to the driver of a fuel-injected car include smoother and more dependable engine response during quick throttle transitions, easier and more dependable engine starting, better operation at extremely high or low ambient temperatures, increased maintenance intervals, and increased fuel efficiency. On a more basic level, fuel injection does away with the choke which on carburetor-equipped vehicles must be operated when starting the engine from cold and then adjusted as the engine warms up.

An engine's air/fuel ratio must be precisely controlled under all operating conditions to achieve the desired engine performance, emissions, derivability, and fuel economy. Modern electronic fuel-injection systems meter fuel very accurately, and use closed loop fuel-injection quantity-control based on a variety of feedback signals from an oxygen sensor, a mass airflow (MAF) or manifold absolute pressure (MAP) sensor, a throttle position (TPS), and at least one sensor on the crankshaft and/or camshaft(s) to monitor the engine's rotational position. Fuel injection systems can react rapidly to changing inputs such as sudden throttle movements, and control the amount of fuel injected to match the engine's dynamic needs across a wide range of operating conditions such as engine load, ambient air temperature, engine temperature, fuel octane level, and atmospheric pressure.
A multipoint fuel injection system generally delivers a more accurate and equal mass of fuel to each cylinder than can a carburetor, thus improving the cylinder-to-cylinder distribution. Exhaust emissions are cleaner because the more precise and accurate fuel metering reduces the concentration of toxic combustion byproducts leaving the engine, and because exhaust cleanup devices such as the catalytic converter can be optimized to operate more efficiently since the exhaust is of consistent and predictable composition.

Fuel injection generally increases engine fuel efficiency. With the improved cylinder-to-cylinder fuel distribution, less fuel is needed for the same power output. When cylinder-to-cylinder distribution is less than ideal, as is always the case to some degree with a carburetor or throttle body fuel injection, some cylinders receive excess fuel as a side effect of ensuring that all cylinders receive sufficient fuel. Power output is asymmetrical with respect to air/fuel ratio; burning extra fuel in the rich cylinders does not reduce power nearly as quickly as burning too little fuel in the lean cylinders. However, rich-running cylinders are undesirable from the standpoint of exhaust emissions, fuel efficiency, engine wear, and engine oil contamination. Deviations from perfect air/fuel distribution, however subtle, affect the emissions, by not letting the combustion events be at the chemically ideal (stoichiometric) air/fuel ratio. Grosser distribution problems eventually begin to reduce efficiency, and the grossest distribution issues finally affect power. Increasingly poorer air/fuel distribution affects emissions, efficiency, and power, in that order. By optimizing the homogeneity of cylinder-to-cylinder mixture distribution, all the cylinders approach their maximum power potential and the engine's overall power output improves.

A fuel-injected engine often produces more power than an equivalent carbureted engine. Fuel injection alone does not necessarily increase an engine's maximum potential output. Increased airflow is needed to burn more fuel, which in turn releases more energy and produces more power. The combustion process converts the fuel's chemical energy into heat energy, whether the fuel is supplied by fuel injectors or a carburetor. However, airflow is often improved with fuel injection, the components of which allow more design freedom to improve the air's path into the engine. In contrast, a carburetor's mounting options are limited because it is larger, it must be carefully oriented with respect to gravity, and it must be equidistant from each of the engine's cylinders to the maximum practicable degree. These design constraints generally compromise airflow into the engine. Furthermore, a carburetor relies on a restrictive venturi to create a local air pressure difference, which forces the fuel into the air stream. The flow loss caused by the venturi, however, is small compared to other flow losses in the induction system. In a well-designed carburetor induction system, the venturi is not a significant airflow restriction.

Fuel is saved while the car is coasting because the car's movement is helping to keep the engine rotating, so less fuel is used for this purpose. Control units on modern cars react to this and reduce or stop fuel flow to the engine reducing wear on the brakes.

5.14 **List of sensors**

* 1 Acoustic, sound, vibration
* 2 Automotive, transportation
* 3 Chemical
* 4 Electric current, electric potential, magnetic, radio
* 5 Environment, weather, humidity
* 6 Flow, fluid velocity
* 7 Ionising radiation, subatomic particles
* 8 Navigation instruments
* 9 Position, angle, displacement, distance, speed, acceleration
* 10 Optical, light, imaging
* 11 Pressure
* 12 Force, density, level
* 13 Thermal, heat, temperature
* 14 Proximity, presence
* 15 Sensor technology

5.14.1 **Acoustic, sound, vibration**

* Geophone
* Hydrophone
* Lace Sensor a guitar pickup
* Microphone
* Seismomete
* Accelerometer

5.14.2 **Automotive, transportation**

* Air-fuel ratio meter
* Crank sensor
* Curb feeler, used to warn driver of curbs
* Defect detector, used on railroads to detect axle and signal problems in passing trains
* MAP sensor
* Parking sensors, used to alert the driver of unseen obstacles during parking manoeuvres
* Radar gun, used to detect the speed of other objects
* Speedometer, used measure the instantaneous speed of a land vehicle
* Speed sensor, used to detect the speed of an object
* Throttle position sensor, used to monitor the position of the throttle in an internal combustion engine
* Variable reluctance sensor, used to measure position and speed of moving metal components
* Water sensor or water-in-fuel sensor, used to indicate the presence of water in fuel
* Wheel speed sensor, used for reading the speed of a vehicle's wheel rotation

5.14.3 **Chemical**

* Breathalyzer
* Carbon dioxide sensor
* Carbon monoxide detector
* Catalytic bead sensor
* Chemical field-effect transistor
* Electrochemical gas sensor
* Electronic nose
* Electrolyte–insulator–semiconductor sensor
* Hydrogen sensor
* Hydrogen sulfide sensor
* Infrared point sensor
* Ion-selective electrode
* Nondispersive infrared sensor
* Microwave chemistry sensor
* Nitrogen oxide sensor
* Olfactometer
* Optode
* Oxygen sensor
* Pellistor
* pH glass electrode
* Potentiometric sensor
* Redox electrode
* Smoke detector
* Zinc oxide nanorod sensor

5.14.4 **Electric current, electric potential, magnetic, radio**

* Ammeter
* Current sensor
* Galvanometer
* Hall effect sensor
* Hall probe
* Leaf electroscope
* Magnetic anomaly detector
* Magnetometer
* Metal detector
* Multimeter
* Ohmmeter
* Radio direction finder
* Voltmeter
* Watt-hour meter

5.14.5 **Environment, weather, humidity**

* Dewcheck
* Fish counter
* Gas detector
* Hook gauge evaporimeter
* Hygrometer
* Leaf sensor
* Pyranometer
* Pyrgeometer
* Psychrometer
* Rain gauge
* Rain sensor
* Seismometers
* Snow gauge
* Soil moisture sensor
* Stream gauge
* Tide gauge

5.14.6 **Flow, fluid velocity**

* Air flow meter
* Anemometer
* Flow sensor
* Gas meter
* Mass flow sensor
* Water meter

5.14.7 **Ionising radiation, subatomic particles**

* Bubble chamber
* Cloud chamber
* Geiger counter
* Neutron detection
* Particle detector
* Scintillation counter
* Scintillator
* Wire chamber

5.14.8 **Navigation instruments**

* Air speed indicator
* Altimeter
* Attitude indicator
* Depth gauge
* Fluxgate compass
* Gyroscope
* Inertial reference unit

* Magnetic compass
* MHD sensor
* Ring laser gyroscope
* Turn coordinator
* Variometer
* Vibrating structure gyroscope
* Yaw rate sensor

5.14.9 **Position, angle, displacement, distance, speed, acceleration**

* Accelerometer
* Capacitive displacement sensor
* Free fall sensor
* Inclinometer
* Laser rangefinder
* Linear encoder
* Linear variable differential transformer (LVDT)
* Liquid capacitive inclinometers
* Odometer
* Piezoelectric accelerometer
* Position sensor
* Rotary encoder
* Rotary variable differential transformer
* Selsyn
* Sudden Motion Sensor
* Tilt sensor
* Tachometer
* Ultrasonic thickness gauge

5.14.10 **Optical, light, imaging**

* Charge-coupled device
* Colorimeter
* Contact image sensor
* Electro-optical sensor
* Flame detector
* Infra-red sensor
* LED as light sensor
* Nichols radiometer
* Fiber optic sensors
* Photodetector
* Photodiode
* Photomultiplier tubes
* Phototransistor
* Photoelectric sensor
* Photoionization detector
* Photomultiplier
* Photoresistor

* Photoswitch
* Phototube
* Proximity sensor
* Scintillometer
* Shack-Hartmann
* Wavefront sensor

5.14.11 **Pressure**

* Barograph
* Barometer
* Boost gauge
* Bourdon gauge
* Hot filament ionization gauge
* Ionization gauge
* McLeod gauge
* Oscillating U-tube
* Permanent Downhole Gauge
* Pirani gauge
* Pressure sensor
* Pressure gauge
* Time pressure gauge

5.14.12 **Force, density, level**

* Bhangmeter
* Hydrometer
* Force gauge
* Level sensor
* Load cell
* Magnetic level gauge
* Nuclear density gauge
* Piezoelectric sensor
* Strain gauge
* Torque sensor
* Viscometer

5.14.13 **Thermal, heat, temperature**

* Bolometer
* Calorimeter
* Exhaust gas temperature gauge
* Gardon gauge
* Heat flux sensor
* Infrared thermometer
* Microbolometer
* Microwave radiometer
* Net radiometer

* Resistance temperature detector
* Resistance thermometer
* Silicon bandgap temperature sensor
* Temperature gauge
* Thermistor
* Thermocouple
* Thermometer

5.14.14 **Proximity, presence**

* Alarm sensor
* Bedwetting alarm
* Motion detector
* Occupancy sensor
* Passive infrared sensor
* Reed switch
* Stud finder
* Triangulation sensor
* Touch switch
* Wired glove

5.14.15 **Sensor technology**

* Active pixel sensor
* Machine vision
* Biochip
* Biosensor
* Capacitance probe
* Catadioptric sensor
* Carbon paste electrode
* Displacement receiver
* Electromechanical film
* Electro-optical sensor
* Fabry–Pérot interferometer
* Image sensor
* Inductive sensor
* Intelligent sensor
* Lab-on-a-chip
* Leaf sensor
* Micro-sensor arrays
* RADAR
* Sensor array
* Sensor grid
* Sensor node
* Soft sensor
* Staring array
* Transducer
* Ultrasonic sensor

* Video sensor
* Visual sensor network
* Wheatstone bridge
* Photo elasticity

5.15 λ control of engine

5.15.1 Problem Specification and Objective

The objective is to find a control structure that can control lambda in a cylinder individual way. This shall be done in three stages:

*Cylinder individual lambda control using a UEGO (Universal Exhaust Gas Oxygen) sensor at the confluence point and UEGO sensors located close1 to each cylinder.

*As above but the cylinder by cylinder placed sensors have an unknown offset.

*Cylinder individual lambda control using a UEGO sensor at the confluence point and cylinder individual lambdas estimated by an ionization current algorithm developed by Mecel AB.

The possibility to accomplish the last stage depends on the complexity of the control problem and the work done by Mecel AB in developing an ionization current algorithm.

To get some results to compare the cylinder individual controller with, the following stages shall be performed first:
*Conventional lambda control using an EGO (Exhaust Gas Oxygen) sensor at the confluence point.

* As above but with a UEGO sensor.

5.15.1.1 Limitations

Below are the most important limitations listed :

*Locked fuel map and ignition angle during experiments.

*No exhaust gas recirculation (EGR).

*Control at three operating points.

* Lambda correction time limited to ±2 ms.

* Not a perfectly tuned throttle control.

* All controllers use a reference value corresponding to $\lambda = 1$ in order to simplify comparisons between different control structures.

* A limited sample rate of about 2000 Hz in the real time system.

* A resolution of 4:88 mV in the D/A card corresponding to a 0:5 % error in lambda for worst case.

5.15.2 Methods

Controlling lambda includes a lot of difficulties to deal with. For example, fuel injections taking place at discrete moments, non linearity's in sensors and engine dynamics, systems (cylinders) running parallel to each other, lambda control gives only a limited correction to the basic injection time and cycle to cycle variations. Note that we can't measure the A/F ratio in the mixture entering the cylinders, which we want to control. We can only measure the oxygen content in the exhaust gases and by this gain information about the A/F ratio.

To simplify the work we only use standard PI controllers. The reason for not using PID controllers is that there is a high noise level in the laboratory and derivation a noisy signal causes problems. Recall that more sophisticated methods like LQG - design always contain P and I parts as basic blocks. This shows that studying PI control is a good first approach. Remember: try simple things first.

5.15.3 Automotive Fundamentals

5.15.3.1 History

Back in the early 1980s almost every automobile engine had a carburetor to meter the air mass flow to fuel mass ow ratio (A/F ratio). It's important to keep the A/F ratio in the vicinity of 15:1 to achieve good engine performance and low emissions. New federal exhaust pollution regulations in California made it hard for the car manufacturers to fulfill these regulations using the old carburetor technique. The change to fuel injectors and electronic fuel control made it possible to use feedback control to meet the new demands.

Due to even more decreasing levels of allowable exhaust pollutants the requirements for accurate A/F ratio control have become very strict over the last decade. A catalytic converter was introduced in the late 1970s to lower exhaust emissions. Especially the three-way catalytic converter made it possible to dramatically reduce the exhaust emissions.

The best commercial system of today uses a three-way catalytic converter combined with fuel injectors and an A/F ratio sensor to perform acceptable feedback control.

To approve new automobiles they are tested in different test cycles e.g.USA-FTP 75 and EEC/EU. The test cycles are designed to imitate real driving conditions i.e. city driving and highway driving. During the tests the exhaust gases are collected in sample bags. A direct comparison of the various emissions regulations is made difficult by differences between test cycles and associated differences in engine load. However, it can be maintained that the most stringent of current limits are those applied in USA.

5.15.4 **Main Parts for A/F Control in an SI Engine**

Below are the most important physical components, concerning A/F control, and their locations in the engine described together with a brief explanation of the four stroke principle.

Air enters the cylinder via the throttle and the inlet manifold, When the throttle is closed we say that the throttle angle is zero and a wide open throttle means 90˚ throttle angle. To fully understand an engine cycle we split the process into four stages. First we have the induction stroke.
Induction stroke:

Intake valve: opened
Exhaust valve: closed
Piston travels: downwards
Combustion: none

Now air can flow into the cylinder and fuel is injected by a fuel injector. When the piston reaches bottom dead center the inlet valve closes and the process moves into the second stage.

Compression stroke:
Intake valve: closed
Exhaust valve: closed
Piston travels: upwards
Combustion: initial ignition phase

About 30{40 crankshaft degrees before top dead center the compressed air fuel mixture is ignited by the spark plug. The third stage is the power stroke.

Power stroke:
Intake valve: closed
Exhaust valve: closed
Piston travels: downwards
Combustion: completed

The high pressure created by the burning mixture forces the piston downward. It's only during this stroke that actual power is generated by the engine. When the piston, for the second time, reaches bottom dead center the exhaust valve opens. Now we have reached the final fourth stage.

Exhaust stroke:
Intake valve: closed
Exhaust valve: opened
Piston travels: upwards
Combustion: none
The upward moving piston forces burned gases from the cylinder through the exhaust manifold into the catalytic converter and out the tailpipe into the atmosphere. Remember that one complete engine cycle requires two complete crankshaft rotations of 360˚ each.

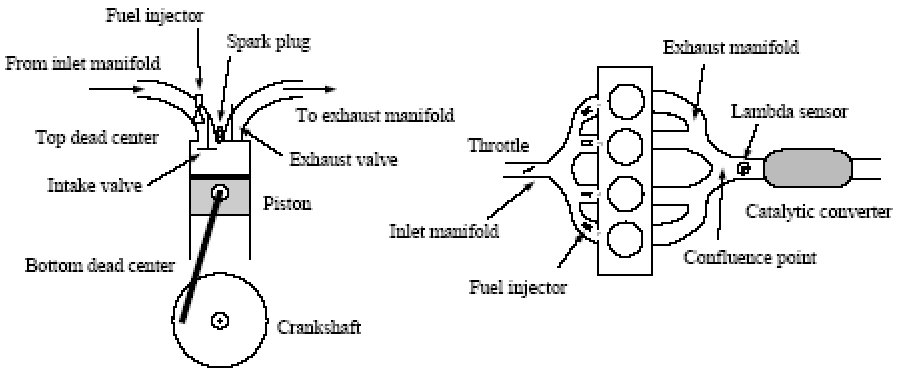


Figure 2.1. Principle sketch of a modern SI engine.

What is λ ?

The A/F ratio is defined as the ratio between air mass flow, m_a, and fuel mass flow, m_f.

$$\text{Air/Fuel ratio (A/F)} = \frac{\dot{m}_a}{\dot{m}_f}$$

Stoichiometry is the optimal mixture of air and fuel in which, when ignited, all of the carbon and hydrogen would completely burn, yielding only carbon dioxide and water. The stoichiometric value depends on the quality of the gasoline, but is normally between 14:57 and 14:70. In other words, about 10000 liters of air are required to support combustion in one liter of fuel!

The parameter λ (lambda) is the A/F ratio normalized with the stoichiometric value which yields:

$$\lambda = \frac{\frac{\dot{m}_a}{\dot{m}_f}}{(\frac{\dot{m}_a}{\dot{m}_f})_s}$$

When λ exceeds 1 the mixture is called lean and in the same way it's called rich when λ is lowers than 1. Under normal driving conditions λ varies from about 0:8 to 1:25. A really lean mixture (λ > 1:3) ceases to be ignitable and misfire starts to occur. Maximum power is produced under a rich mixture when λ is between 0:8 and 0:9. To reach the economy range, without losing drivability, one has to redesign the engine for lean burn purposes.

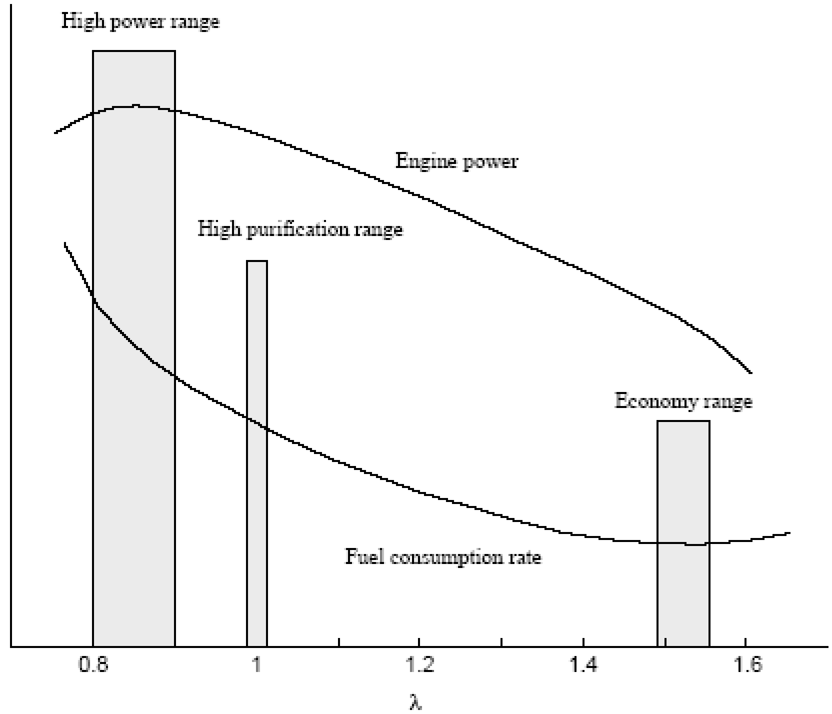


Figure 2.2. Engine power and fuel consumption rate versus λ.

Different Driving Modes:

During a ride the engine operates in many different driving modes. Below is a description of the most commonly used modes:

* Cold start occurs when starting a cold engine. Since the engine isn't warm, fuel will condensate on the walls in the cylinders which require more fuel to be injected. Also if the input air temperature is low problems with vaporization of the fuel must be considered.

*Part-throttle operation is the normal driving mode. Now we have a compromise between low fuel consumption and pollutions. Regulations require a low pollution grade which implies a precise control of λ around the stoichiometric value,

* With acceleration we mean suddenly opened throttle valve. The engine should respond by providing its maximum torque. Figure 2.2 shows a necessity to enrich the air-fuel mixture to $\lambda \approx 0{:}85$.

5.15.5 Three-Way Catalytic Converter

The main task for a catalytic converter is to reduce the emissions of at least one of the following substances: carbon monoxide (CO), hydrocarbons (HC) and oxides of nitrogen (NOx). One wants to remove CO because it's a toxic gas and HC and NOx because they conduce to producing smog. There is one catalytic converter, the three-way catalytic converter (TWC), that can, when operated under certain conditions, simultaneously remove all three pollute components to a high degree.

5.15.5.1 Operating Conditions

Optimal operating temperature for the catalytic converter is between 400-800 ˚C but Catalytic conversion starts at 250 ˚C. If operating temperatures above 800 ˚C are used the thermal aging increases severely. In general, a catalytic converter can under ideal operating conditions have a service life of up to 100000 km,.

5.15.5.2 The Narrow Operating Window

The above mentioned certain conditions for the TWC are illustrated in Figure 2.3. What one can see is that λ must be held within a very narrow window at the stoichiometric ratio. The width of the window is, for 80 % conversion efficiency for all three pollutants, approximately 0:7 % in λ . This accuracy of the λ control is today practically impossible to achieve without using sophisticated model based controllers in a laboratory environment. Practical experience shows that the narrow window can be broadened to 7 % in λ if oscillations are introduced in λ . The frequency of these oscillations should be about 0:5-1 Hz.

5.15.5.3 Electronic Control Unit, Sensors and Actuators

Below we will describe how the electronic control unit performs fuel control using fuel injectors and lambda sensors
.

5.15.5.4 Electronic Control Unit

The electronic control unit (ECU), see Figure 2.4, is a microprocessor based controller with a real time system. Examples of input signals are:
* throttle valve position α.
* inlet manifold absolute pressure, p_{man}.
* engine coolant temperature.
*engine speed, rpm.

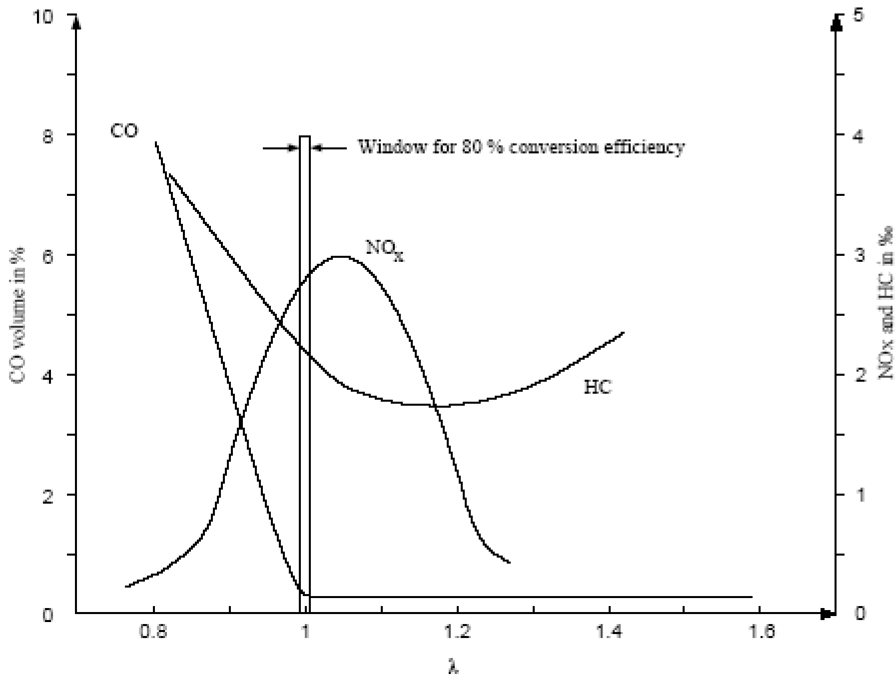


Figure 2.3. The narrow operating window for a TWC. Values of CO, NO_x and HC are shown before a catalytic conversion has occured.

* Exhaust Gas Recirculation, EGR, valve position.
*signals from oxygen sensors.

There are of course also output signals to actuators3 like:

* fuel metering control.

* ignition control and timing.

*exhaust gas recirculation control.

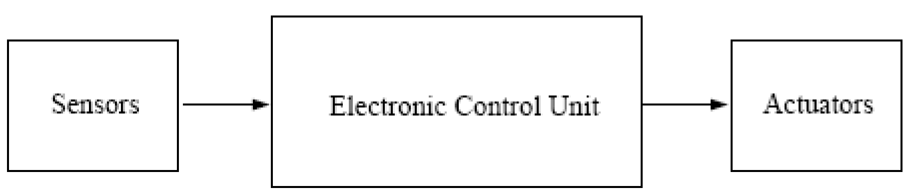


Figure 2.4. Principle sketch of the ECU with sensors and actuators.

Among many other things the ECU performs calculation of correct amount of fuel to be injected into the cylinders. It starts with a basic injection time found in a look up table (fuel map) using engine speed and inlet manifold absolute pressure as input parameters. A basic injection time is always found in the fuel map4 and since we don't have a feedback signal we call it open loop control.

During some driving modes (e.g. part{throttle operation) the fuel injection system works in a closed loop using the lambda sensor output as a feedback signal. The feedback signal is only allowed to correct the basic injection time by approximately 25%. The reason to use feedback is to correct for offsets that might occur due to engine wear or different environmental conditions.

5.15.5.5 Sensors

There are primarily two types of lambda sensors available which differ in price and performance. They both work by measuring the oxygen concentration (they are sometimes called oxygen sensors) in the exhaust gases. The amount of oxygen after combustion is uniquely coupled to the air fuel mixture and we can therefore gain information about lambda by studying exhaust gases.

The exhaust gas oxygen (EGO) sensor is a discrete sensor with switching point around the stoichiometric value, see Figure 2.5. It gives a high voltage signal (≈0:9 V) When $\lambda < 1$ and a low voltage signal (≈ 0:1 V) when $\lambda > 1$. Since the EGO signal behaves like a relay we can only sense a lean or rich air fuel mixture. Almost every modern SI engine equipped automobile uses an EGO sensor because it gives acceptable performance at a low cost.

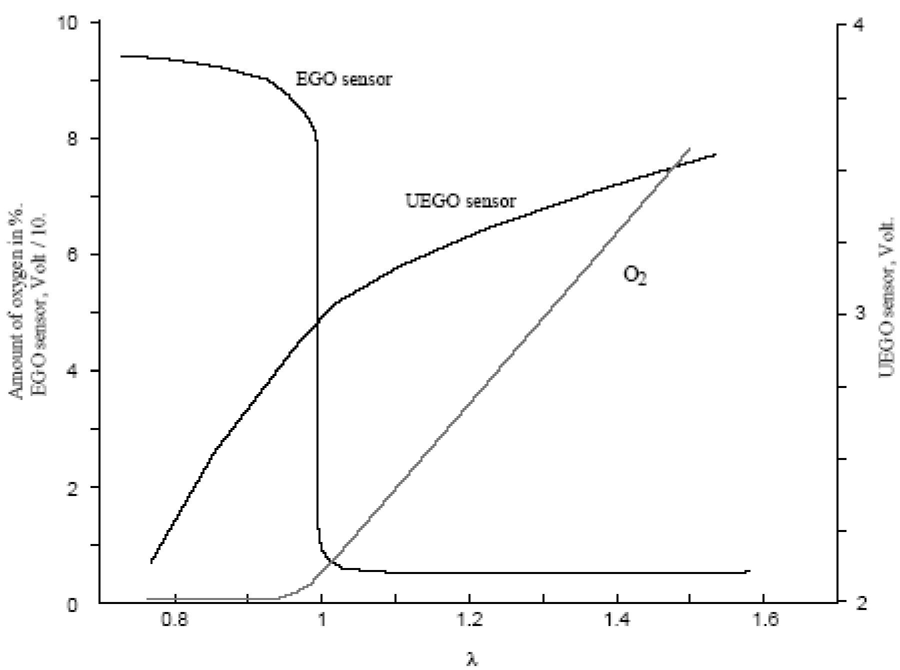


Figure 2.5. Characteristics for EGO and UEGO sensors.

The other type of sensor is the universal exhaust gas oxygen (UEGO) sensor, sometimes called a linear oxygen sensor. We note that the behavior is continuous and we can measure an absolute lambda value over the engines whole operating range ($0{:}8 < \lambda < 1{:}3$). Both EGO and UEGO sensors need an operating temperature above 400˚ C. Most of today's sensors are preheated to quickly reach an acceptable working temperature, but it's still one of the reasons to use open loop control during cold starts.

Lambda sensors don't instantaneously adjust to a change in air fuel mixture. That because of two reasons: first the sensor has a time constant of about 0:1 s, then one has to consider the transport delay when exhaust gases travel from the cylinder to the location of the sensor. Thus we can model a linear lambda sensor as

$$\frac{1}{1+0.1s}e^{-st_{del}}.$$

:

We see that simply by moving the sensor further upstream the exhaust manifold there is a possibility to achieve faster lambda control.

5.15.5.6 Fuel Injectors

Each fuel injector is essentially an electrically actuated valve. When activated the valve opens and fuel is sprayed into the air owing into the cylinder. The time a fuel injector is open is determined by the duration of the activation signal. Because the fuel pressure is constant, the amount of fuel actually injected by the fuel injector depends solely upon the valves open time (injection duration). Thus the ECU can perform fuel calculation using fuel time rather than fuel volume. The injection time is in the range $4 < t_{inj} < 10$ ms. Opening of the valve isn't instantaneous, it has a time delay of about half a ms. This delay may vary with the fuel injectors age due to wear.the valves open time (injection duration). Thus the ECU can perform fuel calculation using fuel time rather than fuel volume. The injection time is in the range 4 < tinj < 10 ms. Opening of the valve isn't instantaneous, it has a time delay of about half a ms. This delay may vary with the fuel injectors age due to wear.

5.15.5.6.1 Opening Experiments

Here we present the results from some opening experiments like open loop control and step response tests. We also describe the chosen operating points, some definitions and the Ziegler-Nichols rules of thumb.

5.15.5.6.2 Operating Points

Three operating points are chosen. They are characterized by (speed, p_{man}). The three points are presented in Table 3.1. In this table we also present the corresponding values for engine torque, M, throttle angle ,α , and total fuel injection time, t_{inj}, giving $\lambda \approx 1$. The operating points are chosen in such a way that they cover the most interesting parts

speed [rpm]	p_{man} [kPa]	M [Nm]	α°	t_{inj} [μs]
1500	60	80	25	6750
2250	40	50	26	4500
3000	60	100	34	7750

Table 3.1. The chosen operating points.

Of the engines operating range. The reason for not choosing a higher speed is that when running at high speed (≥ 3500 rpm) the used electronic throttle control is unreliable. From now on the operating points are called 1500, 2250 and 3000 for convenience. The steps in α during closed loop control are 3˚around the values given in Table 3.1.

5.16 Open Loop Control

During open loop control no lambda feedback is used and the injection times are determined only by the fuel map values. The goal with the project is to eliminate differences between cylinders and since differences in our test engine are small (4 % in stationary and 10 % during transients in lambda) we add offsets to the actual fuel injection times making some cylinders lean and others rich. In Table 3.2 we see the chosen offset times. They result in cylinder individual lambdas between 0:93 (for cylinder 1) and 1:11 (for cylinder 3) in stationarity. At the confluence point lambda tends to be slightly rich. To keep lambda at the same values independent of operating point, different offsets in

Operating point	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4
1500	600	250	−500	600
2250	500	250	−250	250
3000	500	250	−500	500

Table 3.2. Offset fuel injection times, in μs.

injection times are used. Figure 3.1 shows lambda values during open loop control with offset times added at 1500 rpm. This is a typical lambda behavior. Notice the differences between single cylinders and that the mean value for lambda at the confluence point is
far from 1.

5.17 Single Sensor Lambda Control

In this section we implement the conventional lambda control used in production automobiles to compare with our designed controllers. Differences between control using EGO and UEGO sensor are shown both in simulations and by experimental results.

5.17.1 Conventional Lambda Control

By conventional lambda control we mean the combination of a single EGO sensor and an I or PI controller. The reason for studying conventional lambda control is that we need a controller to compare our controllers properties with. First we use only an I controller, limit cycle control, and then we also introduce a P part, jump back control.

5.17.2 Limit Cycle Control

When combining a relay like feedback signal with a system with a pure transport delay and an I controller so called limit cycles occur. Below are the period and amplitude for the oscillations in the controller output derived. To simplify the calculations the engine is assumed to have a transfer function equal to 1 and the EGO sensor is assumed to behave like a perfect relay. The EGO sensor output is 1 when $\lambda < 1$ and 0 when $\lambda > 1$. The transport delay, t_{del}, is in this example 1 s and Ti in Equation 3.1 is 10. The system is illustrated in Figure 5.1. The controller output is a correction to the fuel injection time picked from the fuel map. The air mass flow is constant in this example. The first approach, using describing function, see [6], to calculate the period, doesn't

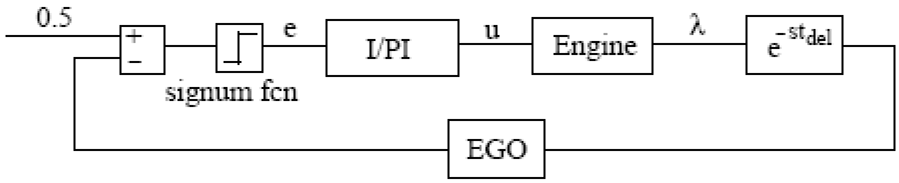


Figure 5.1. A principle sketch of EGO sensor control.

work because the system doesn't have low pass properties. Instead we use a heuristic method to calculate the period and amplitude. In Figure 5.2 λ , the controller output,u, and the EGO sensor output are shown. At A λ switches from rich to lean. When the influence of the lean mixture reaches the EGO sensor at B, it switches to 0 (lean) and the controller starts to enrich the mixture. At C λ switches from lean to rich and again it takes 1 s, corresponding to the transport delay, before the EGO sensor switches at D. The controller now starts to make the mixture more lean and at E λ again switches from rich to lean. This is observed at the EGO sensor at F. In Figure 5.2 we see that the period, T, is equal to four times the time delay

$$T = 4t_{del}.$$

This means that the shorter the transport delay is, the higher the frequency of the limit cycles will be. The transport delay decreases as engine speed increases, which implies higher frequencies at higher engine speeds. If the engine and sensor dynamics are faster than the transport delay, Equation 5.1 gives a good approximation of the transport
delay.

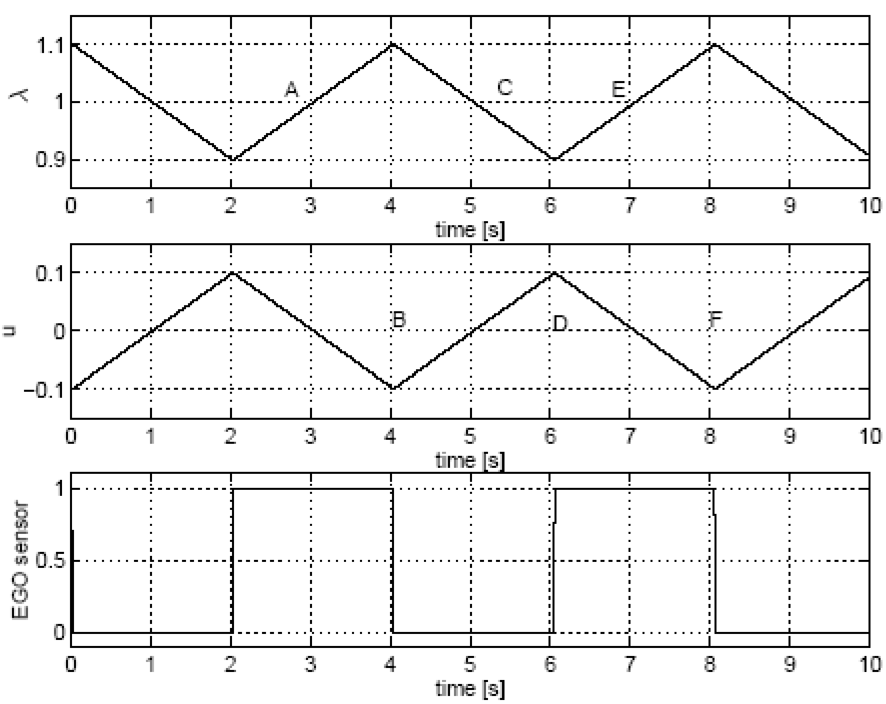


Figure 5.2. Illustration of the limit cycle phenomena.

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To calculate the amplitude in the controller output we note that the time the EGO sensor output is constant corresponds to two times the transport delay. During this time the controller output goes from its maximum to its minimum or vice versa, thus

$$u_{p-p} = \frac{2t_{del}}{T_i}e.$$

Now we see that by choosing a bigger value of Ti we get a smaller amplitude in u and therefore also in λ. Unfortunately this only holds in theory and not practically due to disturbances and dynamics in sensors and in the engine. The choice of Ti is also a
compromise between good transient behavior and small variations in λ under stationary
conditions. Since we are mostly interested in the latter we choose a Ti such that choosing a bigger Ti will not give significantly smaller variations in λ at stationarity.

5.18 Jump Back Control

To achieve better transient properties we also add a proportional part to the controller.
By choosing the proportional part in a smart way we can double the oscillation frequency but still have the same oscillation amplitude.

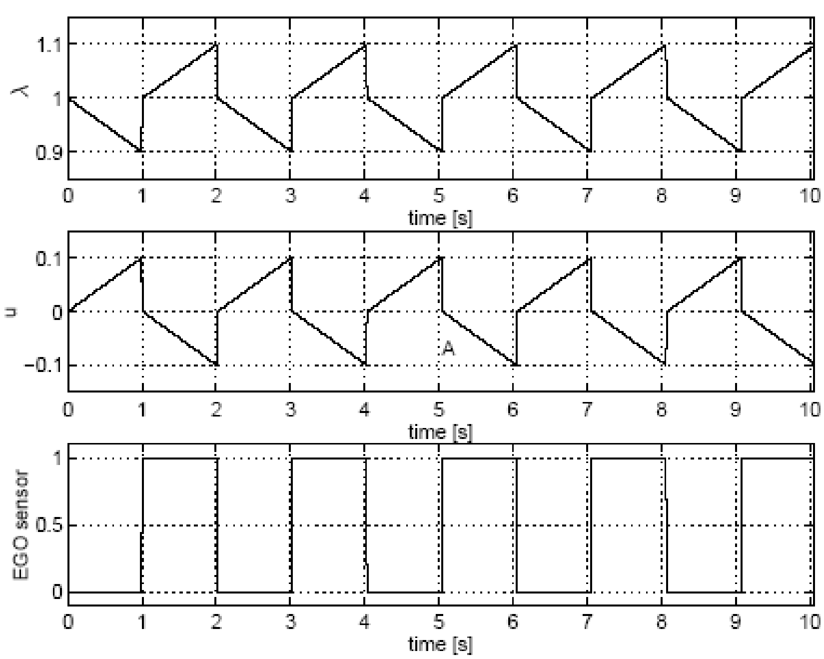


Figure 5.3. Illustration of jump back control.

5.19 Lambda Control Using One UEGO Sensor

When using a UEGO sensor we are able to get absolute lambda values over the entire engine operating range. More information about the process should lead to better controlling results. Phenomena like limit cycles and jump back are no longer present. By not relying on a switching point we are able to give the regulator an input reference in lambda not equal to 1, although $\lambda_{ref} = 1$ is used during both simulations and engine testing.

5.19.1 The Control Structure

Figure 5.9 shows the control structure used in this section for lambda control with a UEGO sensor. We use $1/\lambda$ rather than λ as an input signal because $1/\lambda$ is proportional

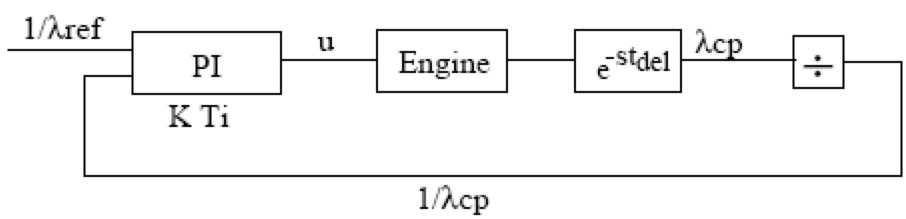


Figure 5.9. Structure of the single UEGO sensor controller.

to the amount of fuel ($1/\lambda = 14{:}57/(A/F) \approx F/\text{constant}$, for a given throttle angle). A calculated output signal affects all four fuel injectors and no consideration is taken to cylinder individual differences.

5.20 Multi Sensor Lambda Control

In this section we will show one way to use all information from five lambda sensors to perform cylinder individual lambda control. By a slight modification of the regulator code we also show how the control structure deals with an unknown offset added to measurements of the cylinder individual lambdas. This is done to prepare for an exchange of UEGO measured lambda to lambda estimated by an ionization current A/F algorithm.

Previous we have only used one sensor located slightly downstream the confluence point in the exhaust manifold to perform lambda control. The major benefit of using one sensor for each cylinder is the possibility to eliminate single cylinder differences.

Another benefit is shorter transport delay between combustion and measurement. One might wonder if there are any differences between cylinders in an engine? Yes there are! When an engine is new differences are small and may be caused by e.g. on homogenous heat distribution. Differences grow when the engine gets older, due to wear in fuel injectors, inlet valves etc. In [5] the authors talk about differences up to ±5% between single cylinders. Since our test engine is quite new we simulate these differences by adding an, for the regulator, \unknown" offset to each cylinder injection time making some cylinders rich and others lean.

5.20.1 The Control Structure

This control structure is developed to handle cylinder individual differences in lambda.The structure is common for both the all information regulator and the regulator that has an unknown offset added to its measurements of lambda. As before we use the linearization of UEGO sensors done by the volt2lambda function. The regulator consists of four inner PI regulators, one for each cylinder, which can be viewed as four separate inner loops, and one outer PI regulator, see Figure 6.1. The inner loops force the cylinder individual lambdas to the same value and the outer loop controls lambda at the confluence point to the desired reference value. The integral (I) part in each regulator is needed for keeping the operating point and we use _ve integral parts because λ_i= 1 for i = 1,…., 4 may not always result in λ_{cp} = 1! We also use proportional (P) parts to enhance performance during transients. The reason for not using derivating (D) parts is that the system contains a lot of noise and it's a well known fact that derivating a noisy signal tends to cause problems. Thus we have the same principle control law as before

$$u(t) = Ke(t) + \frac{1}{T_i}\int_0^t e(\tau)d\tau.$$

The output signal from the outer regulator is provided as an input signal to the inner loops. The outer regulator uses feedback from the UEGO sensor located downstream the confluence point in the exhaust manifold. These signals together with the reference signal, in lambda, are input signals to the outer regulator. Based on the difference between reference signal and feedback lambda it creates an input signal for the four inner loops. The inner loop regulators use reset anti wind up because they have limitations in their allowed output signals of± 2 ms. When having more than one integrating part in a control structure one must consider the fact that the integrating parts can start interacting with each other. It's best understood with an example. Let's form the output signal from the first inner regulator

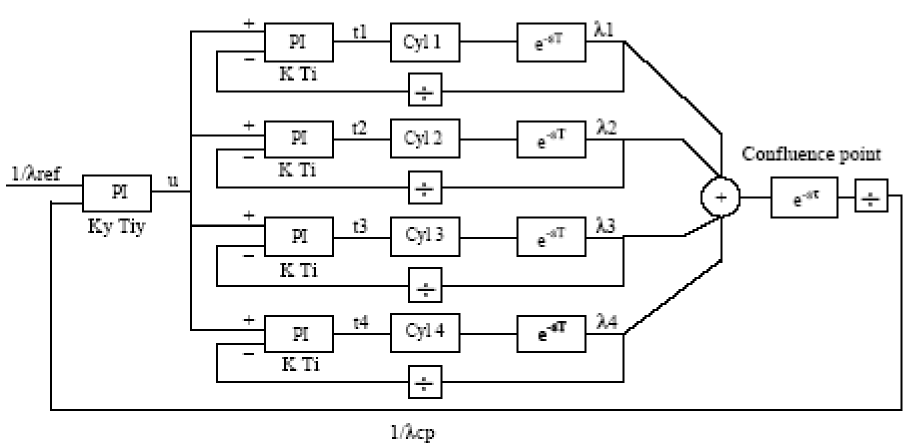


Figure 6.1. Structure of the multi sensor controller.

Loop.

5.21 Ignition control of engine

Introduction:

The spark plug can be used as a sensor during the part of the engine cycle where it is not used for ignition. This is done by setting a small voltage over the spark plug and measuring the current. This current is due to the ions in the gap of the spark plug, and the measurement is called the "ionization current". The ions are formed during and after the combustion, and the type and amount of ions depend on combustion characteristics. The ionization current also depends on the pressure, the temperature, and so on. The signal is thus very rich in information, but it is also complex. It is a fast direct in-cylinder measurement, as opposed to sensors in the exhaust, and it is used on each cylinder individually. The **potential for feed**back control is thus obvious.

5.21.1 Spark- Ignited engines:

In spark-ignited (SI) internal combustion engines the cylinder is filled with fresh chaxge, which then is compressed. Before the piston has reached the uppermost position, top dead center (TDC), the mixture is ignited by the spark plug. A flame kernel develops in the mixture and turns to a turbulent flame. During combustion, the cylinder pressure rises due to the released energy and the new molecules produced by the chemical reactions. The flame reaches the wall, and the combustion completes. During the compression, work is transferred to the gases within the cylinder, and during the expansion, work is transferred from the gases. A thorough description of the combustion process is given **in (Heywood, 1988).**

5.21.2 Cylinder pressure

The cylinder pressure is an important parameter in the combustion, since it gives the work produced by the combustion. In Figure 1 (a) three different pressure traces are displayed. The lowest dash-dotted trace, the motored cycle, is obtained by running the engine with an electric motor without firing the engine. The two other traces are from cycles when firing occurs. Two different ignition timings produce the signals shown; the dashed trace has an early timing and the solid line has an ignition timing that is optimal. The optimal ignition timing is called the "maximum brake torque timing" (MBT). A pressure trace with late ignition timing is shown by the dashed line in Figure 1 (b).

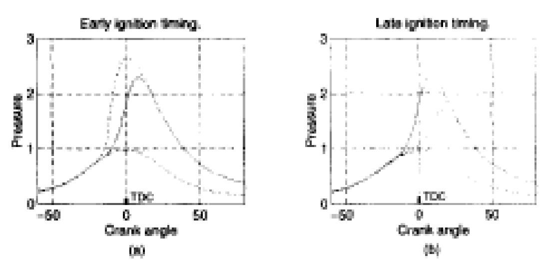


Fig. 1. The cylinder pressure showing the motored cycle and three different positions for the ignition. (a) Motored cycle, MBT and early timing. (b) Motored cycle, MBT and late timing.

The influence of ignition timing on the work produced can be seen in Figure 1. With early ignition the pressure increases too early, before TDC, and work is lost during the compression of the gases. With too-late ignition **work is lost due to the** later pressure rise, after TDC.

5.21.3 Ignition control

In SI engines the ignition timing is an important parameter, among others, **for the** combustion efficiency. The ignition timing alone affects almost every engine output. In nearly all of today's production engines there is no feedback from the combustion to the ignition timing; the spark advance is based on a pre-calibrated system.

Several parameters affect the best spark advance setting, such as engine speed, load, air/fuel ratio, fuel characteristics, EGR, coolant temperature, air temperature, and humidity, among others. Present ignition-control systems measure several of these parameters, and adjust the spark advance. The spark advance setting is obtained by extensive testing and calibration during the design phase of the engine. Provided that all the parameters affecting the ignition timing were measured, and that all interactions were properly accounted for, it would be possible to determine the best spark advance. However, it is not possible to measure and account for all the parameters, since it would be extremely expensive to perform the measurement and testing required to incorporate such a system in a production engine.

The testing and calibration results in a nominal spark advance schedule. The schedule is conservative, since it has to guarantee that knock (or detonation) does not occur, as well as good performance over the entire range of the non-measured parameters. These systems are only calibrated during the design of the engine, and there is no feedback in the ignition control.

5.21.4 Peak pressure algorithm

A fundamentally different approach is to utilize the cylinder pressure as the sensed variable for the ignition control. As indicated earlier, the best ignition timing will position the pressure time history in some optimal way. Research in this area has shown that the position for the peak pressure is almost constant at optimal spark timing (Hubbard *et al.*, 1976). A spark control algorithm that maintains a constant pressure peak position (called the peak pressure algorithm), results in an ignition timing that is within 2' of optimum. The algorithm also results in optimal ignition timing for large changes in parameters that affect the flame speed, such as the fuel/air ratio and air humidity (Hubbard et *al., 1976;* Glaser and Powell, *1981).* Humidity is interesting, since it represents the largest environmental disturbance to optimal ignition timing.

The optimum value for the peak pressure position, between 12° and 20° after TDC, varies with engine designs, mainly due to different heat flows to the cylinder walls (Powell, 1993). The influence of cycle – by - cycle variations, in peak pressure position (θ_{pp}) with constant ignition timing, shall not inflect the ignition timing (IT) by more than 1°. Hence, cyclic variation of the order of 10° results in feedback to the ignition timing with a constant $\Delta IT = \frac{1}{10}\Delta\theta_{pp}$ where θ_{pp} = (desired θ_{pp})-(measured θ_{pp}) and ΔIT= (change in ignition timing) (Powell, 1993). The peak pressure algorithm suffers from the fact that a pressure sensor that could stand the high temperatures and pressures would be very expensive. One manufacturer has implemented the concept and reported a 10% improvement in power and 5% improvpment in efficiency **(Sawarnoto** *et al., 1987).*

5.21.5 The ionization current

In an ideal combustion, hydrocarbon molecules react with oxygen and generate carbon monoxide and water. An ideal reaction, with the hydrocarbon isooctane, gives

$$C_8H_{18} + 27/2\ O_2 \rightarrow 8CO_2 + 9H_20.$$

In the combustion there are also other reactions, which go through several steps before they are completed. Several reactions that include ions are present in the combustion; some examples axe **(Shimasaki** *et al.*, 1993)

$$CH+O \rightarrow CHO^{+} + e^{-}$$

$$CHO^{+} + H_20 \rightarrow H_30^{+} + CO$$

$$CH + C_2H_2 \rightarrow C_3\ H_3^{+} + e^{-}$$

These ions, and several others, are generated by the chemical reactions in the flame. Additional ions axe created when the temperature increases as the pressure rises. Thus, more ions are generated at higher internal energy of the gases.

To detect the ions, a DC bias is applied to the **spark plug, generating** an electrical field.

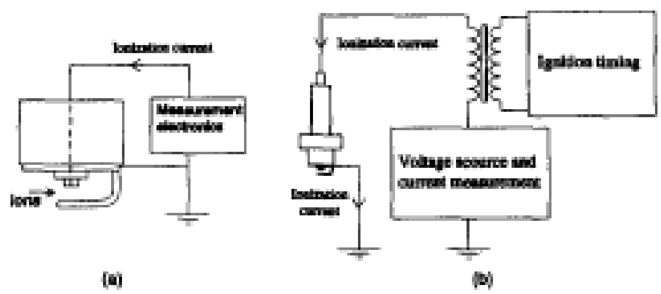


Fig. 2. Measurement of the ionization current.
(a) The spark plug-gap is used as a probe.
(b) Measurement on the low voltage side.

The ionization current is an interesting engine parameter to study, since it contains a lot of information about the combustion. Some of the parameters that affect the ionization current are: temperature, air/fuel ratio, time since combustion, exhaust gas recycling (EGR), fuel composition, engine load, and several others.

5.21.6 The ionization current signal

The ionization current, Fig, 3, has three characteristic phases; ignition, flame front, and post flaine. In the ignition phase, the ionization current is large, with reversed polarity. Due to the high current in the ignition the measured signal shown in the figure is limited. What can be seen in Fig. 3 is the ringing phenomenon in the coil after the ignition. The high level of ions associated with the chemical reactions in the flame produces one or more characteristic peaks in the flame-front phase. The ions generated by the flame have different recombination rates. Some ions recombine very quickly to more-stable molecules, while others have longer residual times. The result is a high peak, that decays and flattens out when only the n!iore stable ions remain.

In the post-flanie phase the most stable ions remain, generating a signal that follows the cylinder pressure due to its effect on the molecule concentration. Ions axe also created by the measurement voltage and the high temperature of the burned gases, since the temperature follows the pressure **during the** compression of the burned gases, i.e., when the flame propagates outwards and the combustion completes. The ionization, current will hence depend on the pressure. The relatively low ionization energy of NO makes it a contributor to the ionization current in the post-flame phase **(Saitzkoff** *et al.*, 1996).

5.21.6.1 Experimental situation

The engine used for measurement and validation is a spark-ignited, SAAB 2.3 1, 16-valve, fours troke, four-cylinder, fuel-injected, normally aspirated, production engine equipped with the Trionic engine control system. The ionization current measurement system is the production system developed by Mecel AB (Gillbrand *et al., 1984)*, which is used in the SAAB engine. A pressure transducer and amplifier from AVL, for in-cylinder pressure measurement, is used for validation of the algorithms. A cog wheel is attached to the crank, and an inductive sensor is used for computing the engine position. The experimental setup is shown in Figure **4.**

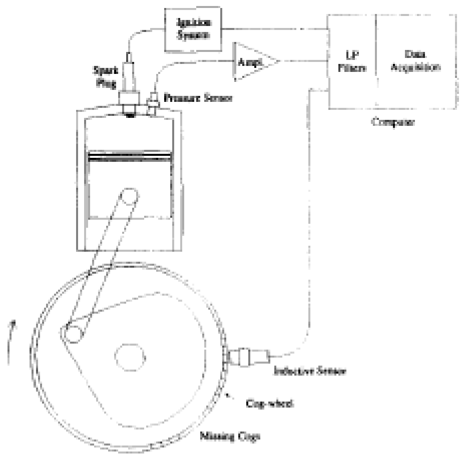


Fig. 4. The measurement situation. The pressure sensor is used only for validation.

The data was collected at several operating points in the mid -load and mid -speed range for the engine. The engine speed was in the range 2000 rpm to *4500* rpm, and the brake torque was in the range 50 Nm to *150* Nm. Approximately 100 cycles for each operating point were collected and evaluated.

5.21.7 Ionization current interpretation

The ionization current is affected by several parameters other than the cylinder pressure. Aiming at ignition control, using the ionization current and the peak pressure algorithm, special care must be taken when extracting the pressure information from the ionization current.

5.21.8 Connection between ionization and pressure

As mentioned earlier, and displayed in Figure *5,* the pressure has most influence on the post - flame phase of the ionization current. Problems occur when searching for the peak pressure position: a peak search is not feasible since the flame - front phase often consists of more than one peak, and the post-flame phase often appears without a peak. In Figure 6 an ionization current signal with two peaks in the flame front and no peak in the post flame is displayed. It can be seen that the ionization signal contains information about the pressure in the post-flame phase, despite the fact that the post-flame phase does not contain a peak.

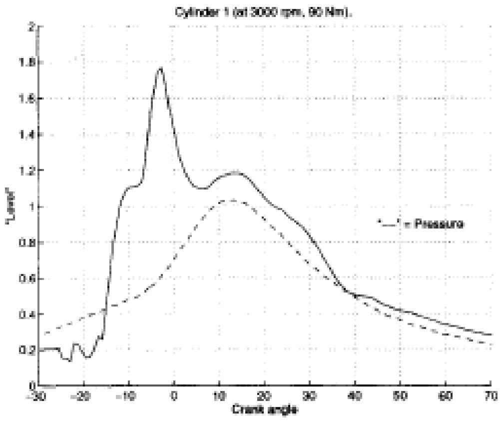


Fig. 5. Ionization current and cylinder pressure for one cycle. The post-flame phase corresponds to the pressure.

5.21.9 A model of the ionization signal

An analytical expression for the ionization current has been presented (Saitzkoff *et al., 1996),* assuming that the gas in the spark plug is fully combusted, in thermodynamic equilibrium, and it undergoes adiabatic expansion, also assuming that the current is carried in a cylinder extending from the central electrode of the spark plug. Given the cylinder pressure, the analytical expression for the

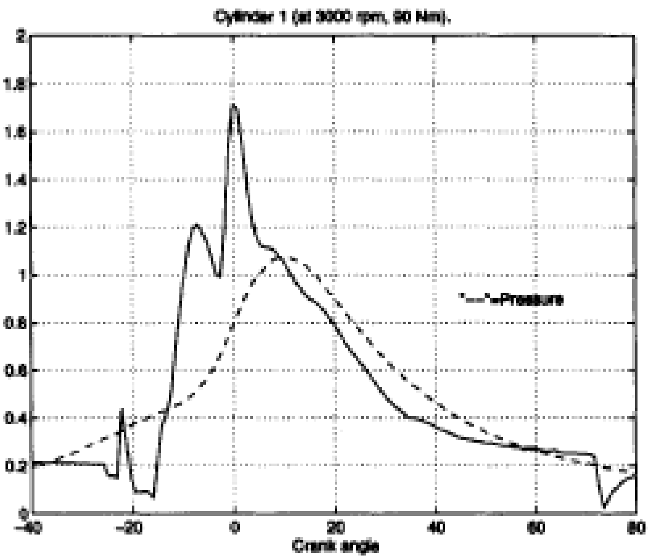


Fig. 6. A case where the ionization current has two peaks in the flame-front phase and no peak in the post-flame phase, but there is still a correspondence with the pressure.

ionization current is

$$\frac{I}{I_m} = \frac{1}{(\frac{p}{p_m})^{\frac{1}{2}-\frac{3}{4}\frac{\gamma-1}{\gamma}}} e^{-\frac{E_i}{2kT_m}\left[(\frac{p}{p_m})^{-\frac{\gamma-1}{\gamma}}-1\right]}.$$

The variables and constants are: I, Ionization current; I_m, Ionization current maximum; p, Cylinder pressure; p_m, Cylinder pressure maximum; T_m, Maximum temperature; γ, Specific heat ratio; k, Boltzmann's constant; E_i, Ionization energy.

Using the function and the measured cylinder pressure, the component of the ionization current related to the cylinder pressure has a shape close to a Gaussian function. In Figure 7 a Gaussian function is compared to the signal received by the pressure. Therefore, an idealized model of the ionization current, contains a Gaussian-shaped function for the component connected to the pressure. To the model, a description f (θ) of the flame front must also be added,

$$I(\theta) = f(\theta) + \beta_1 e^{-(1/\beta 2)(\theta-\beta s)2} \qquad (2)$$

(? denotes the crank angle). A simple flame-front model is a Gaussian signal, which can capture a high peak in the flame front which decays. Thus the model is

$$I(?) = \alpha_1 e^{-(1/\alpha 2)(\theta-\alpha s)2} + \beta_1 e^{-(1/\beta 20(\theta-\beta s)2} \qquad (3)$$

Conclusions

It has been demonstrated that it is feasible to use ionization current interpretation for spark advance control to optimize engine performance. The proposed method is very cost -effective, since it uses exactly the same hardware and instrumentation (already used in production cars) that is used to employ the spark plug as a sensor for misfire detection and knock control.

It is also clear that, once the phase of the ionization current that is related to pressure development has been extracted, there is still a lot of information available in the signal. Ongoing and future work will, of course, try to utilize this information, not only for ignition timing control, but also for other measures of combustion characteristics e.g. for use in EGR and air/fuel control.

Chapter 6

Engine characteristics & trouble shooting

6.1 Engine model & serial number:

(1) The engine model and serial number is located on the engine as illustrated.
(2) These numbers are required when requesting warranty and orderly parts. They are also referred to as engine model and serial number because of their location.

6.2 Engine characteristic:

The natural gas engine is an overhead valve, turbo charged, water-to-air charge cooled, electronically controlled engine.

6.3 Design characteristic:

(1) Spark-ignited by the spark plug.
(2) Electric engine control through the ECM (engine control module) system.
(3) Turbocharger with water cooled bearing-housing.

6.4 Natural gas:

(1) Natural gas is a clean burning fuel and offers a low particulate emission. Natural gas is also a very economical fuel..
(2) From the gas producing areas in the country, the distribution companies and local utilities from a complex nation-wide-delivery-network that supplies natural gas to home and industry use. The network is highly developed and extended to a major population center in the country.

6.5 Valves:

The overhead valves are actuated via chilled cast iron tappets, push rods and rocker arms from the camshaft.

6.5.1 Engine lubrication system:

(1) The engine is equipped with force-feed lubrication .The pressure is produced by gear pump whose drive gear is in direct mesh with the crankshaft gear at the flywheel end.
(2) The oil pump draws the oil from the oil sump and delivers it through the oil filter and oil cooler to the main distributor gallery and from there to the main bearing big-end bearing and camshaft bearing as well as to the small-end bearing and the rocker arms.
(3) The turbocharger is also connected to the engine lubricating system. The cylinder walls and timing gears are splash-lubricated.
(4) Each cylinder has an oil jet provided for cooling the underside of the piston. The lube oil is cleaned in a full-flow oil filter.
(5) Depending on the agreed extent of delivery and the design of the engine, the lube oil circuit can be equipped with oil pressure monitors(advance warning and cut off function)which shut the engine down in the event of a sudden loss of pressure.

6.6 Engine oil:

(1) Check oil level with the oil level gauge and replenish if necessary.
(2) Check the oil level with the engine cooled. If the engine is warm, allow time for 5-10 minutes for oil drain into the crankcase before checking oil level. The oil level must be between MAX .and MIN. lines on the gauge.
(3) Engine oil should be changed at the specified intervals. Oil in the oil filter cartridge should be changed simultaneously.

6.7 Exchanging of lubrication oil

(1) Engine oil and the oil filter are important factors affecting engine life. They affect ease of starting, fuel economy, combustion chamber deposits and engine wear.
(2) While the oil is still hot, discharge the sump oil by motion oil drain pump lever manually as figure.
(3) Refill new engine oil to the filter neck on the head cover in accordance with the oil capacity of the engine. Be careful about the mixing of the dust or contaminator during the supplement of oil. Then confirm whether the oil level gauge indicates the vicinity of its maximum level.
(4) For a few minutes, operate the engine at idling in order to circulate oil through lubrication system. Thereafter shut down the engine. After waiting for about 10 minutes measure the quality of oil and refill the additional oil if necessary.

6.8 **Replacement of oil filter cartridge:**

(1) Every time oil exchanges, replace the oil filter cartridge.
(2) Drain engine oil by loosing the drain plug on the filter head.

Caution:

Don’t forget tightening the drain plug after having drained engine oil.

(1) Remove the oil filter by turning it counter-clockwise with a filter wrench.
(2) Wipe; clean the fitting face of the filter body with a rag so that the new oil filter cartridge can be seated properly.
(3) Lightly oil the O-ring and turn the oil filter until O-ring is fitted against the seal face. And then turn it addition by 3/4-1 turns further with hand or the filter wrench.

Note:

It is strongly advisable to use genuine oil filter cartridge for replacement.

6.9 Cooling System:

(1) The engine has a liquid-cooling system. The water pump is a maintenance-free impeller pump driven by V-belts from the crankshaft pulley.
(2) Depending on the agreed extent of delivery and the design of the engine, the coolant circuit can be equipped with temperature monitors which in the event of loss of coolant shut the engine down.

6.10 Cooling water:

(1) Regarding the cooling water that is to be used for engine, the soft water not the hard water must be used.
(2) The engine cooling water can be used diluting it with antifreeze solution 40% and the additive for rust prevention (DCA4)3~5%.
(3) The density of above solution and additive must be inspected every 500 hours the maintain it properly.

Note:

The proper density control of antifreeze solution and rust preventing additive will be able to prevent the rusting effectively and maintain the stable quality of engine.
For the improper control might give the fatal damage to the cooling water pump and cylinder liners, detail care is needed.

(1) Since E2848, E2840, E2842 cylinder liners are wet type, particular the cooling water control should be applied thoroughly.
(2) The density of antifreeze solution and additive for rust prevention is able to be confirmed by the cooling water test kit.

6.11 How to the cooling water test kit:

(1) When the cooling temp. of engine is in the range of 10 ~ 55º loosen the plug for cooling water discharge and fill the plastic cub about a half.

NOTE:
In taking the cooling water sample, if the water in auxiliary tank were taken, it is heard to measure the accurate density. Take the cooling water sample necessarily loosening the cooling water discharge plug.

(2) At the state of a test paper soaked in the sampled water , after taking the paper out through water agitation, shake off the water.
(3) Wait for about 45 sec. till the color change of the test paper .

Note:
However, it should not elapse longer than 75 sec, and if it did, the due would change.

(4) Make the numerical value by comparing the test paper which hue has changed with the color list of label on storage bottle.
(5) By comparing the hue changed into yellowish green or so with the green color indication of test paper storage bottle, confirm the density.(Then, the density indication must be in the hue range of 33% to 50%)
(6) The brown at the middle test paper and the lower pink color indication represent the additive state for rust prevention , and the proper range is the

meeting numerical value of brown (vertical) and pink color (horizontal) locates in the range of 0.3 to 0.8 at the color list of label on the test paper storage bottle..
(7) In case of less than 0.3, replenish the additive for rust prevention (DCA) and in case of more than 0.8, pour out the cooling water about 50% and the readjust the density after refilling with clean fresh water.

6.12 V-belt:

(1) Use a V-belt of specified dimensions, and replace if damaged, frayed, or deteriorated.
(2) Check the V-belt for belt tension. If belt tension is lower than the specified limit, adjust the tension by relocating the alternator. (Specified deflection: 10~15 min when pressed down with thumb)

6.13 Air Cleaned:

(1) Air cleaned is mounted on the engine to purify the air for combustion. The intervals at which the air cleaner requires servicing depend on the specific operating conditions encountered. Clogged air filters may cause black smock and reduce powder.
(2) A check should be made from time to time to see that the fastening elements securing the air cleaner to the intake manifold seal the connection tightly. Any ingress of unfiltered air is liable to cause a high rate of cylinder and piston wear.

6.14 Valve clearances adjust procedure:

(1) After letting the #1 cylinder's piston come at the compression top dead center by turning the crankshaft, adjust the valve clearances.
(2) Loosen the lock nuts of rocker arm adjusting screws and push the feeler gauge of specified value between a rocker arm and a valve stem and adjust the clearance with adjusting screw respectively and then tighten with the lock nut .
(3) As for the valve clearance, adjust it when in cold , as follows.

Model	Intake Valve	Exhaust Valve
E2848		
E2840	.30 mm	.40 mm
E2842		

6.15 Adjusting Sequence of Valve Clearance (1 type):

(1) By cranking the engine, let #1 cylinder's valves overlap.
(2) In time adjust the valve clearance corresponding to lower lists.
(3) In time, turning crankshaft one full turn let the valves of #7 or #6 cylinder's valve overlap.
(4) Adjust the valve clearance of lower lists.
(5) After reinsuring the valve clearance, retighten if necessary.

6.16 Adjusting Sequence of Valve Clearance (2 type):

Type 1 is the conventional and simple method, but if you have some problem to adjust your engine, please tries type 2 sequence. This is a precision method, but it takes more time.

Cylinder Compression Pressure:

(1) Stop the engine after warming up, take out the spark plug.
(2) Install the special tool (compression gauge adapter) at the spark plug hole, and connect the compression pressure gauge there.

Condition:

Water temperature 20ºC, Engine rotation 200rpm.

6.17 Battery:

(1) Inspect for any leakage of electrolytic solution owing to battery crack, and replace the battery in case of poor condition.
(2) Inspect for amount of electrolytic solution, replenish if insufficient.
(3) Measure the gravity of electrolytic solution, if less than specified value (1.12-1.28) replenish.

6.18 Turbocharger:

(1) The turbocharger needs not arty special equipment.
(2) Every time of engine replacement, a leakage or clogging of oil pipes should be inspected. Air cleaner should be maintained carefully for nut or foreign material not to get in. Periodic inspection should be applied on the compressed air and exhaust gas pipes. For leaking air will bring the overheat engine, an immediate repair must be done.
(3) During the operation that is surrounded by the dust and oil mixed air, frequent cleaning must be done on the impellers. Tear down the impeller casing (attention be careful not to bend) and must clean with non-acid solvent solution. If necessary use plastic scraper if impeller is severely polluted, dip the impeller into solution and may be better to clean it with stiff brush. Then one thing to beware is to dip only impeller part and so do not support by impeller but bearing housing.

6.19 Alternator:

(1) The alternator is fitted with integral silicon rectifiers. A transistorized regulator mounted on the alternator body interior limits the alternator voltage. The alternator should not be operated except with the regulator and battery connected in circuit to avoid damage to the rectifier and regulator.
(2) The alternator is maintenance free, nevertheless, it must be protected against dust and, above all, against moisture and water.

6.20 Starting motor:

(1) The sliding gear started motor is flanged to the rear of the flywheel housing on the left-hand side. As part of every engine overhaul, the starter pinion and ring gear should be cleaned with a brush dipped in fuel and then a coat of greases should be applied again.
(2) Always protect starter motor against moisture.

Important:

Always disconnect the battery earth cable before starting work on the electrical system. Connect up the earth cable last, as there is otherwise a risk of short-circuits.

Precautions in use:

(1) Pay attention to dropping the battery voltage capacity when they are left for long time even without use.
(2) As starting may not be done well something in cold winter season, do not try it to be continuous immediately but try to start again after waiting about 30 seconds.
(3) Prior to operating the gauge panel, make sure the polarity of battery once again.(In majority of polarities, red side is “+’’ and black one is “-’’)
(4) On disassembling the gauge panel may be accompanied a risk of electrical shock, always work after pulling off the connector at rear side of it without fail.
(5) If the silver paper is used for connecting the cut off fuse because the excessive current might flow into the parts of damage, when fuse is cut-off, after resolving the problem locating the cause, replace it with new fuse.
(6) Since battery has a danger of exploration by a heat, it must not be placed at the spot where generates a lot of heat.
(7) When engine is in stop, pull out the key always. Thus, a hazard of fire or wound due to wrong operation may not happen.
(8) In case of scrapping the batteries, observe the following.

Note:

Do not throw it in the fire to scrap. It should not be thrown away into the places where are liable to cause the environmental pollution such as stream, river and mountain. Pack them as far as possible and dispose it as rubbish that is unable to use again.

(1) M.A.N will not be responsible to the problems that might be raised by the disassembling and structural change of this product without consultation.

6.21 Diagnosis and Remedy:

Condition	Causes	Remedies
(1)Starting difficult. Compression Pressure	(1)Valve's poor shut, steam distortion. (2)Valve spring damage (3)Cylinder head gasket's leak (4) Wear of piston, piston ring or liner.	Repair or replace Replace valve spring Replace gasket Adjust
(2) Idle operation abnormal		
(3)Engine output insufficient. (1)Continuous output insufficient	(1) Ignition timing incorrect (2)Valve clearance incorrect (3)Valve tightness poor (4)Cylinder head gasket's leak (5)Wear, stick, damage of piston ring (6)Ignition timing incorrect (7)Damage of spark plug & ignition coil (8)Air suction amount insufficient (9)Turbocharger poor	Adjust Adjust Repair Replace gasket Replace piston ring Adjust Adjust or replace Clean or replace air cleaner Repair or replace
(2)Output insufficient when in acceleration	(1)Compression pressure insufficient. (2)Ignition timing incorrect (3)Damage of spark plug ignition coil (4)Air intake amount insufficient	Disassemble engine Adjust Repair or replace Clean or replace air cleaner
(4)Overheating	(1)Engine oil insufficient or poor (2)Cooling water insufficient (3)Fan belt loosened, worn, damaged (4)Cooling water pump's function lowered (5)Thermostat operation	Replenish or replace Replenish or replace Adjust or replace Repair or replace Replace

	poor (6)Valve clearance incorrect (7)Exhaust system's resistance increased	 Adjust Clean or Replace
(5)Engine noisy	For noises arise compositely such as rotating parts, lapping parts Etc there is necessity to search the cause of noise accurately.	
(1)Crankshaft	(1)As the wear of bearing or crankshaft progress, the oil clearances increase. (2)Lopsided wire of crank pin (3)Oil supply insufficient due to oil passage clogging (4)Stuck bearing	Replace bearing & grind crankshaft Grind or Replace Clean oil passage Replace bearing & grind
(2)Connecting rod & connecting rod bearing	(1)Lopsided wear of con rod bearing (2)Lopsided wear of crank pin (3)Connecting rod distortion (4)Stuck bearing (5)Oil supply insufficiently as clogging at oil passage progress	Replace bearing Grind crankshaft Repair & replace Replace& Grind crankshaft Clean oil passage
(3)Piston, piston pin, piston ring	(1)Piston clearance increase as the wear of piston and piston ring progress (2)Wear of piston or piston pin (3)Stuck piston (4)Piston insertion poor (5)Piston ring	Replace piston and Piston ring Replace Replace piston Replace piston Replace piston
(4)Others	(1)Wear of crankshaft, trust bearing (2)Camshaft end play increased (3)Idle gear end play increased (4)Timing gear backlash excessive (5)Valve clearance excessive (6)Abnormal wear of tappet, cam	Replace trust bearing Replace trust plate Replace trust washer Repair or replace Adjust valve clearance Replace tappet, cam

	(7)Turbocharger inner part damaged	Repair or replace
(6)Oil consumption Excessive		
(1)Oil level elevated	(1)Clearance between cylinder liner & piston	Replace
	(2)Wear of piston ring, ring groove	Replace piston, piston ring
	(3)Piston ring's damage, stick wear	Replace piston ring
	(4) Piston ring opening's disposition improper	Correct piston
	(5)Piston skirt part damaged or abnormal wear	Replace piston
	(6)Oil ring's oil return hole clogged	Replace piston ring
	(7)Oil ring's contact poor	Replace piston ring
(2)Oil level lowered	(1)Looseness of valve stem& guide	Replace in set
	(2)Wear of valve stem seal	Replace in seal
	(3)Cylinder head gasket's leak	Replace in gasket
(3)Oil leak	(1)Looseness of connection parts	Replace gasket, repair
	(2)Various parts' packing poor	Replace packing
	(3)Oil seal poor	Replace oil seal

(1) The following description summarizes the probable cause of and remedy for general failure by item.

(2) Immediate counter measure should be taken before a failure is inflamed if any symptom is detected.

(3) Inspect the electrical parts problem by the display module.

****Engine starting impossible
****Engine overheated
****Output insufficient
****Oil pressure lowered
****Fuel Consumption Excessive
**** Oil Consumption Excessive
****Engine Knocking
**** Battery Discharge

Chapter 7

Alternator Part

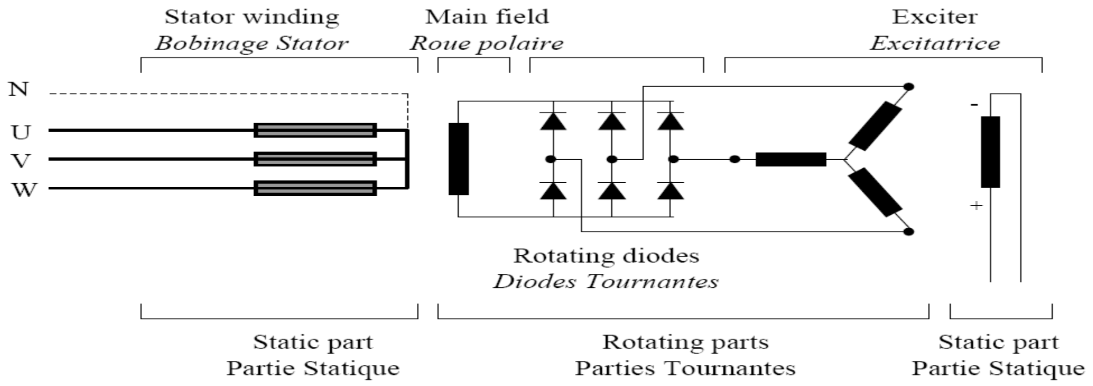
Introduction:

A complete power station can not classified by major and minor components. For our thesis purpose it considered some important familiar components. Although Maximum Protection systems are electromechanical system but here its integrated system discuss by as per as we know.

7.1 **Major electrical components**

7.1.1 Principle of Generator/Alternator:

This system is brush less without pilot exciter system. Without pilot exciter system is a small AC generator. To make the excitation of a generator completely independent of any external power source a small pilot exciter often included in the system. In this figure static part is stator and exciter field, and rotating part is exciter armature, rectifier and main field.



Some residual magnetism contained in the main field. When the prime mover begins to rotate the main field that time main stator induced minimum ac voltage. This ac voltage through Automatic voltage Regulator (AVR) by auxiliary winding then the AVR filtering the harmonics and also rectifying the minimum induced ac voltage. The rectifying dc voltage goes to the exciter field then again induced ac voltage in the exciter armature. the induced ac voltage rectifying by bridge rectifier and finally the rectifying strong dc voltage go to the main field then produced desired voltage from the stator winding.

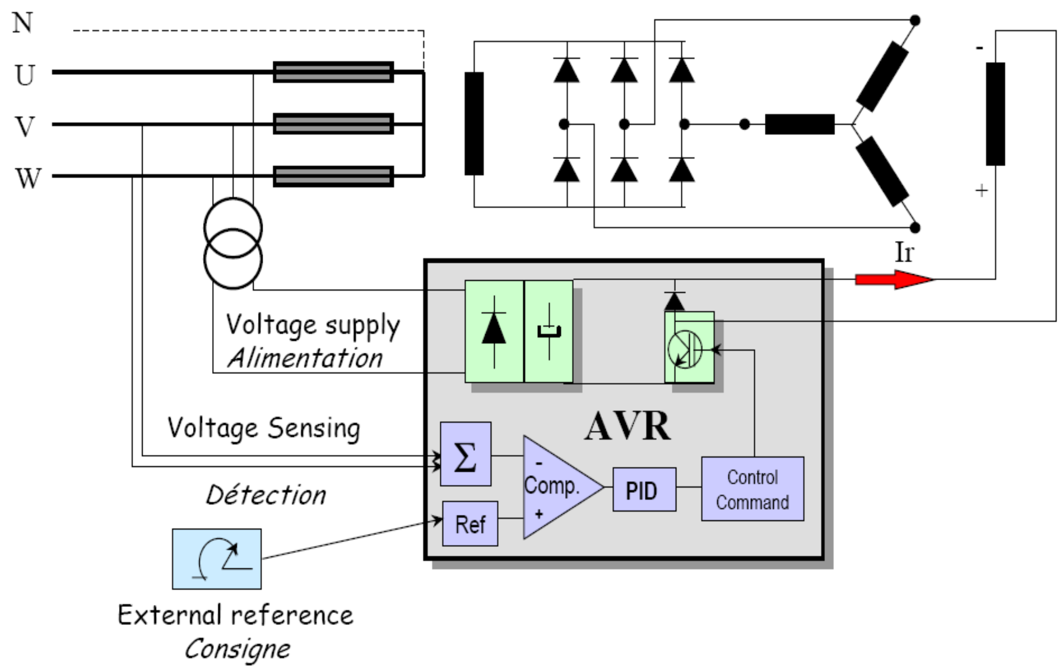


Fig: 7.1 Basic AC generating System

7.1.2 Major Parts of Alternator

AC Generator Means alternator, an **alternator** is an electromechanical device that converts mechanical energy to alternating current electrical energy. Most alternators use a rotating magnetic field but linear alternators are occasionally used. In principle, any AC electrical generator can be called an alternator, but usually the word refers to small rotating machines driven by automotive and other internal combustion engines.

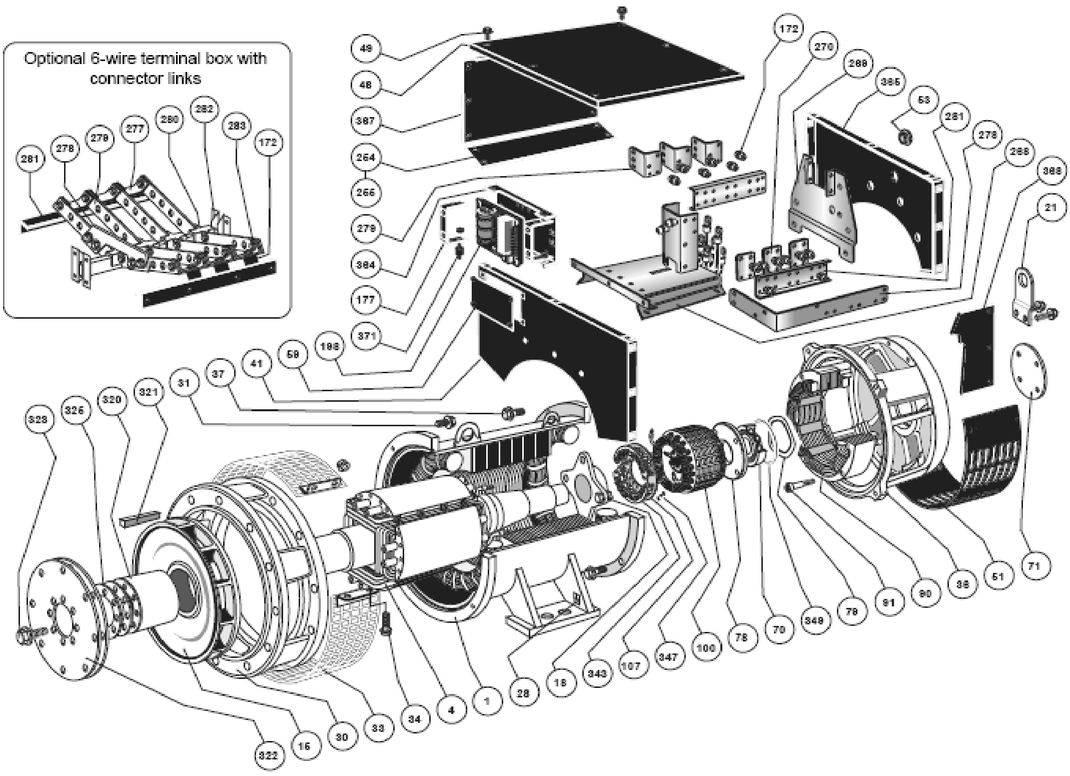


Fig:7.2 Alternator.

7.1.3 Rotor

The rotating part of an alternator, generator, dynamo or motor. The **rotor** is the non-stationary part of a rotary electric motor or alternator, which rotates because the wires and magnetic field of the motor are arranged so that a torque is developed about the rotor’s axis. In some designs, the rotor can act to serve as the motor's armature, across which the input voltage is supplied. The stationary part of an electric motor is the stator. A common problem is called cogging torque.

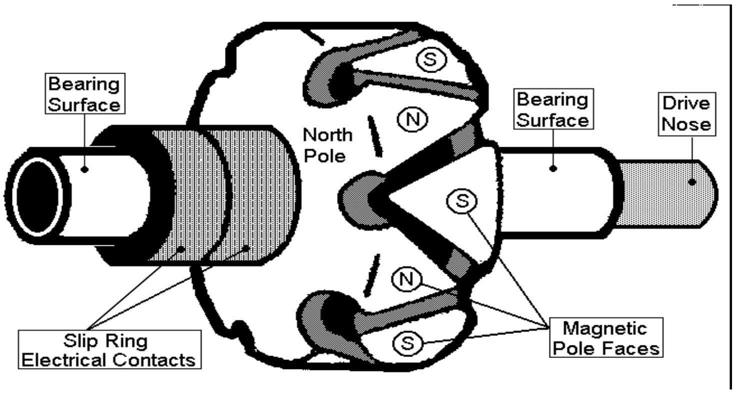


Fig: 7.3 Rotor.

7.1.4 Stator

The stationary part of an alternator, generator, dynamo or motor. The stator is the stationary part of an electric generator or electric motor. The non-stationary part on an electric motor is the rotor. Depending on the configuration of a spinning electromotive device the stator may act as the field magnet, interacting with the armature to create motion, or it may act as the armature, receiving its influence from moving field coils on the rotor.

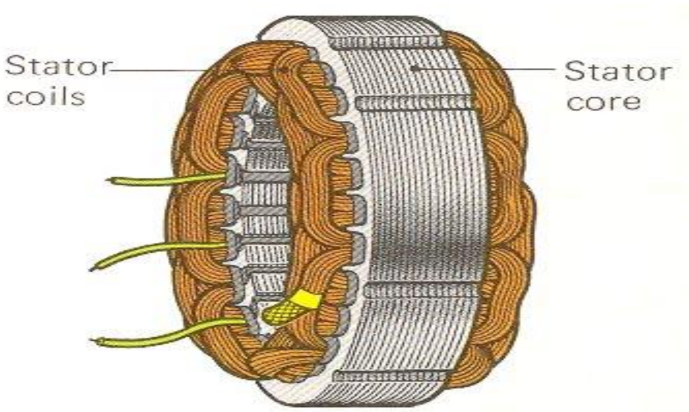


Fig: 7.4 Stator.

The stator of these devices may be either a permanent magnet or an electromagnet. Where the stator is an electromagnet, the coil which energizes it is known as the field coil or field winding. An AC alternator is able to produce power across multiple high-current power generation coils connected in parallel, eliminating the need for the commentator. Placing the field coils on the rotor allows for an inexpensive slip ring mechanism to transfer high-voltage, low current power to the rotating field coil. It consists of a steel frame enclosing a hollow cylindrical core (made up of laminations of silicon steel). The laminations are to reduce hysteretic and eddy current losses.

7.1.5 Armature

The power-producing component of an alternator, generator, dynamo or motor. In a generator, alternator, or dynamo the armature windings generate the electrical current. The armature can be on either the rotor or the stator. In electrical engineering, an armature generally refers to one of the two principal electrical components of an electromechanical machine - a motor or generator, but may also mean the pole piece of a permanent magnet or electromagnet, or the moving iron part of a solenoid or relay. The other component is the field winding or field magnet. The role of the "field" component is simply to create a magnetic field (magnetic flux) for the armature to interact with, so this component can comprise either permanent magnets, or electromagnets formed by a conducting coil. The armature, in contrast, must carry current so it is always a conductor or a conductive coil, oriented normal to both the field and to the direction of motion, torque (rotating machine), or force (linear machine). The armature's role is two-fold: (a) to carry current crossing the field, thus creating shaft torque (in a rotating machine) or force (in a linear machine), and (b) to generate an electromotive force ("EMF"). In the armature, an electromotive force ("EMF") is created by the relative motion of the armature and the field. When the machine is acting as a motor, this EMF opposes the armature current, and the armature converts electrical power to mechanical torque (and power, unless the machine is stalled) and transfers it to the load via the shaft. When the machine is acting as a generator, the armature EMF drives the armature current, and shaft mechanical power is converted to electrical power and transferred to the load. (In an induction generator, these distinctions are blurred, since the generated power is drawn from the stator, which would normally be considered the field.)A growler is used to check the armature for shorts, opens and grounds.

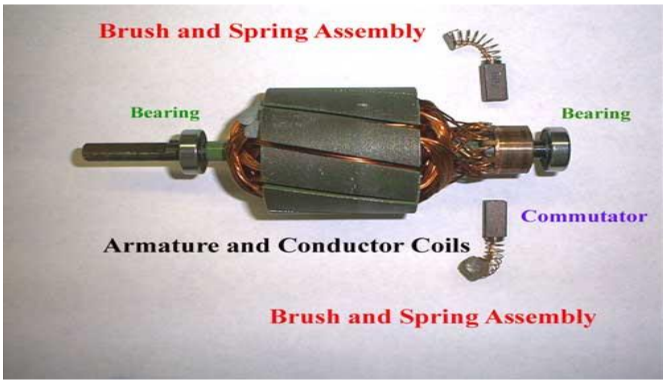


Fig:7.5 Armature

The parts of an alternator or related equipment can be expressed in either mechanical terms or electrical terms. Although distinctly separate, these two sets of terminology are frequently used interchangeably or in combinations that include one mechanical term and one electrical term. This may cause confusion when working with compound machines such as brushless alternators, or in conversation among people who are accustomed to work with differently configured machinery.

7.1.6 Field

The magnetic field component of an alternator, generator, dynamo or motor. The magnetic field of the dynamo or alternator can be provided by either electromagnets or permanent magnets mounted on either the rotor or the stator. (For a more technical discussion, refer to the Field coil article.) Because power transferred into the field circuit is much less than in the armature circuit, AC generators nearly always have the field winding on the rotor and the stator as the armature winding. Only a small amount of field current must be transferred to the moving rotor, using slip rings.

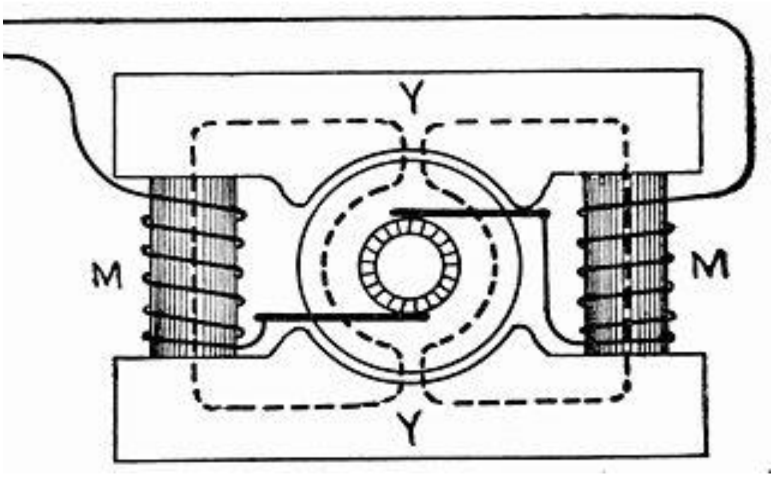


Fig: 7.6 Consequent field bipolar generators

Direct current machines necessarily have the commentator on the rotating shaft, so the armature winding is on the rotor of the machine. A field coil is the magnetic field component of an alternator, generator, dynamo, motor, or rotary converter. The phrase is also often used in the plural form, as field coils. The field coils can be mounted on either the rotor or the stator, depending on whichever method is the most cost-effective for the device design.

Bipolar and Multi-polar Field,

In the early years of generator development, the stator field went through an evolutionary improvement from a single bipolar field to a later multiple designs.

Bipolar generators were universal prior to 1890 but in the years following it was replaced by the multicolor field magnets. Bipolar generators were then only made in very small sizes.

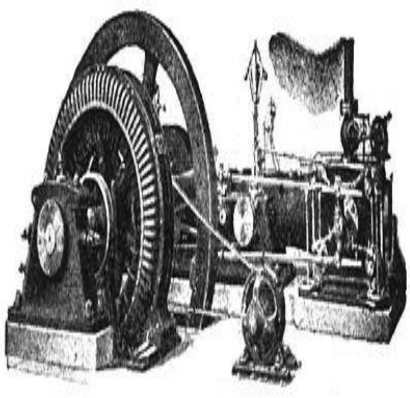
The stepping stone between these two major types was the consequent-pole bipolar generator, with two field coils arranged in a ring around the stator. This change was needed because higher voltages allow current to flow greater distances over small wires. To increase output voltage, a DC generator must be spun faster, but beyond a certain speed this is impractical for very large power transmission generators. By increasing the number of pole faces surrounding the Grammy ring, the ring can be made to cut across more magnetic lines of force in one revolution than a basic two-pole generator.

Consequently a four-pole generator could output twice the voltage of a two-pole generator, a six-pole generator could output three times the voltage of a two-pole, and so forth. This allows output voltage to increase without also increasing the rotational rate. In a multi polar generator, the armature and field magnets are surrounded by a circular frame or ring yoke to which the field magnets are attached. This has the advantages of strength, simplicity, symmetrical appearance, and minimum magnetic leakage, since the pole pieces have the least possible surface and the path of the magnetic flux is shorter than in a two-pole design

7.1.7 Excitation

Excitation System
Three basic types of excitation systems exist to provide DC supply to the field

– Compound
– Shunt (& boost)
– AREP



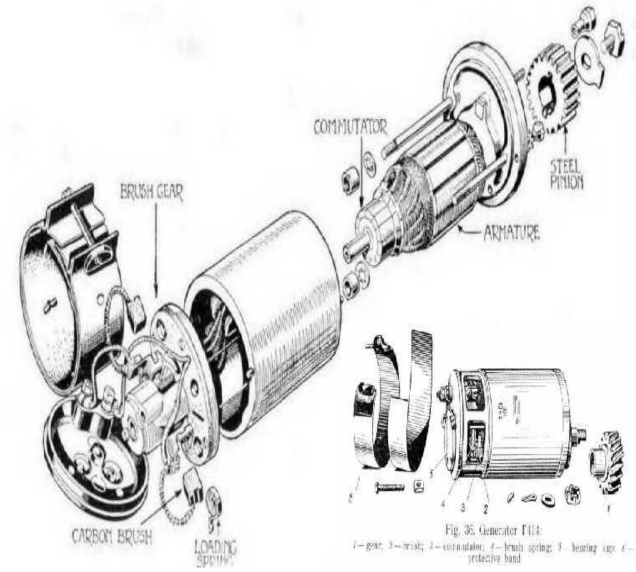
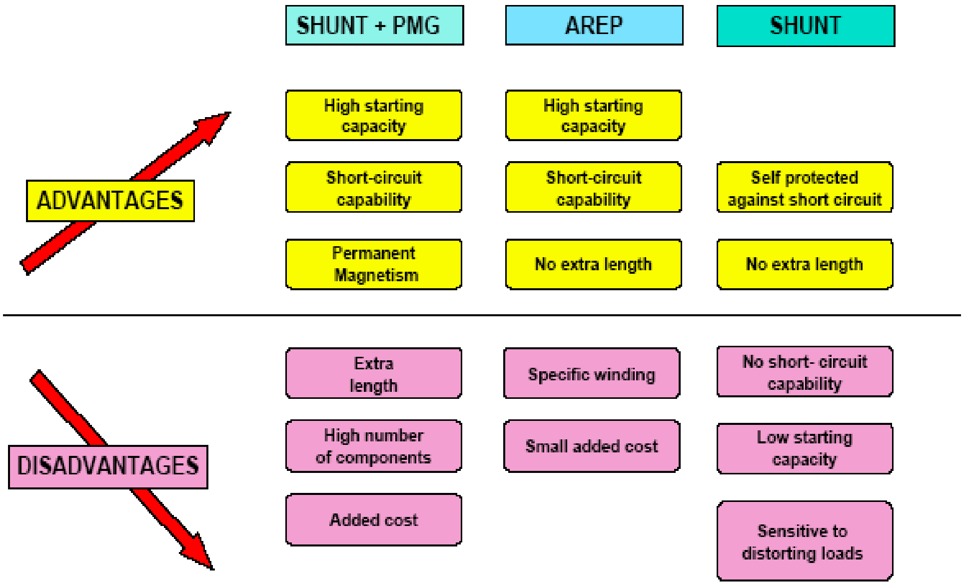


Fig:7.7 Excitation.

A small early 1900s 75 KVA direct-driven power station AC alternator, with a separate belt-driven exciter generator.



An electric generator or electric motor that uses field coils rather than permanent magnets will require a current flow to be present in the field coils for the device to be able to work. If the field coils are not powered, the rotor in a generator can spin without producing any usable electrical energy, while the rotor of a motor may not spin at all. Very large power station generators often utilize a separate smaller generator to excite the field coils of the larger.

In the event of a severe widespread power outage where islanding of power stations has occurred, the stations may need to perform a black start to excite the fields of their largest generators, in order to restore customer power service.

To obtain and maintain a specific AC output voltage, a variable DC source is required to overcome the variation of excitation requirement

Various load conditions:

• Three basic types of excitation systems exist to Main generator + exciter generator = two rotating machines. The magnetic circuit of the exciter and main field maintain sufficient residual magnetism to ensure voltage build up. The stator AC output voltage is rectified through the AVR to provide excitation to the field.
The exciter armature is energized by the DC source applied to the field. The exciter armature AC output is rectified through rotating diodes to provide DC excitation to the main field. The main field by rotating, creates the magnetic flux and the output AC voltage. The stator AC output voltage is in direct relation with the DC voltage provided to the exciter field.

7.1.8 Rectifier

A rectifier is an electrical device that converts alternating current (AC) to direct current (DC), a process known as rectification. Rectifiers have many uses including as components of power supplies and as detectors of radio signals. Rectifiers may be made of solid state diodes, vacuum tube diodes, mercury arc valves, and other components.A device which performs the opposite function (converting DC to AC) is known as an inverter.When only one diode is used to rectify AC (by blocking the negative or positive portion of the waveform), the difference between the term diode and the term rectifier is merely one of usage, i.e., the term rectifier describes a diode that is being used to convert AC to DC. Almost all rectifiers comprise a number of diodes in a specific arrangement for more efficiently converting AC to DC than is possible with only one diode. Before the development of silicon semiconductor rectifiers, vacuum tube diodes and copper (I) oxide or selenium rectifier stacks were used.

Early radio receivers, called crystal radios, used a "cat's whisker" of fine wire pressing on a crystal of galena (lead sulfide) to serve as a point-contact rectifier or "crystal detector". In gas heating systems flame rectification can be used to detect a flame. Two metal electrodes in the outer layer of the flame provide a current path and rectification of an applied alternating voltage, but only while the flame is presentFor three-phase AC, six diodes are used. Typically there are three pairs of diodes, each pair, though, is not the same kind of **double diode** that would be used for a full wave single-phase rectifier. Instead the pairs are in series (anode to cathode). Typically, commercially available double diodes have four terminals so the user can configure them as single-phase split supply use, for half a bridge, or for three-phase use.

Fig: 7.8 Three-Phase Bridge Rectifier.

For three-phase AC, six diodes are used. Typically there are

Disassembled automobile alternator, showing the six diodes that comprise a full-wave three-phase bridge rectifier. Most devices that generate alternating current (such devices are called alternators) generate three-phase AC. For example, an automobile alternator has six diodes inside it to function as a full-wave rectifier for battery charging applications.

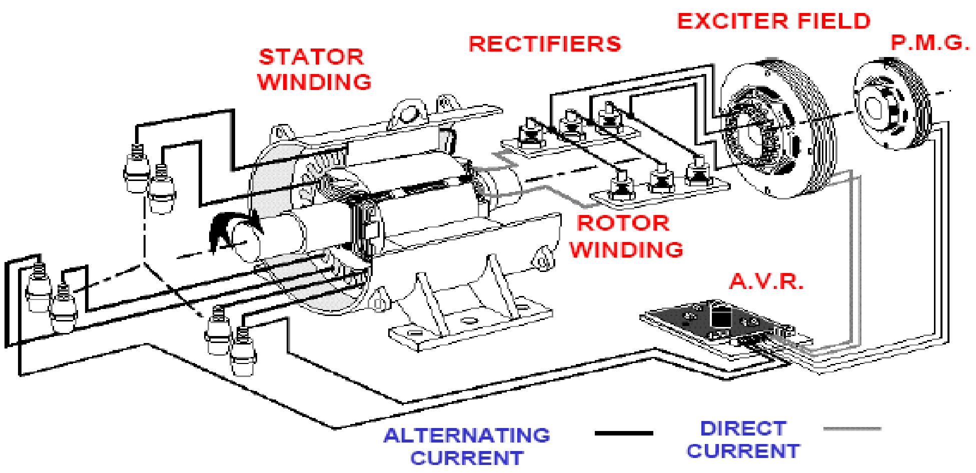


Fig: 7.9 Rectifying System

7.1.9 Principle of AVR

A voltage regulator is an electrical regulator designed to automatically maintain a Constant voltage level.

It may use an electromechanical mechanism, or passive or active electronic components. Depending on the design, it may be used to regulate one or more AC or DC voltages. With the exception of shunt regulators, all modern electronic voltage regulators operate by comparing the actual output voltage to some internal fixed reference voltage. Any difference is amplified and used to control the regulation element. This forms a negative feedback servo control loop. If the output voltage is too low, the regulation element is commanded to produce a higher voltage. For some regulators if the output voltage is too high, the regulation element is commanded to produce a lower voltage; however, many just stop sourcing current and depend on the current draw of whatever it is driving to pull the voltage back down. In this way, the output voltage is held roughly constant. The control loop must be carefully designed to produce the desired tradeoff between stability and speed of response

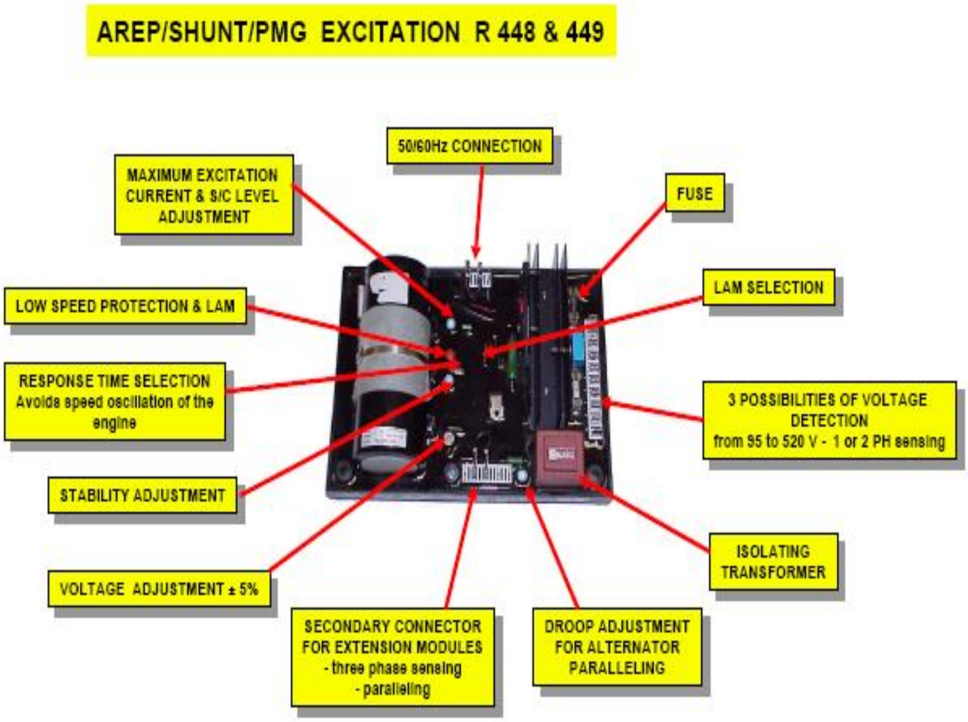


Fig:7.10 Automatic Voltage Regulators.

Coil-rotation AC voltage regulator,

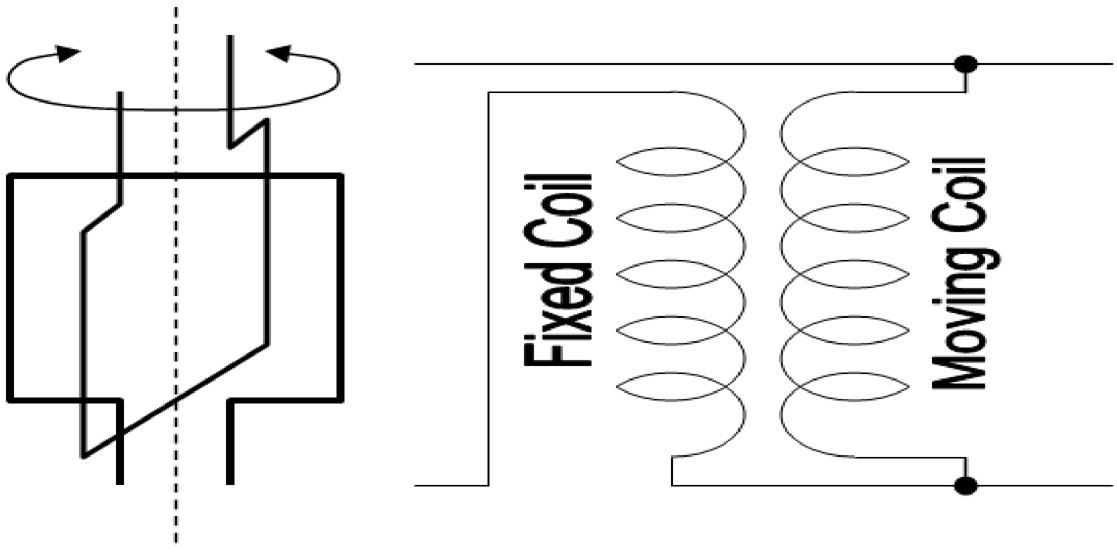


Fig: 6.11 Basic design principle and circuit diagram for the rotating-coil AC voltage regulator.

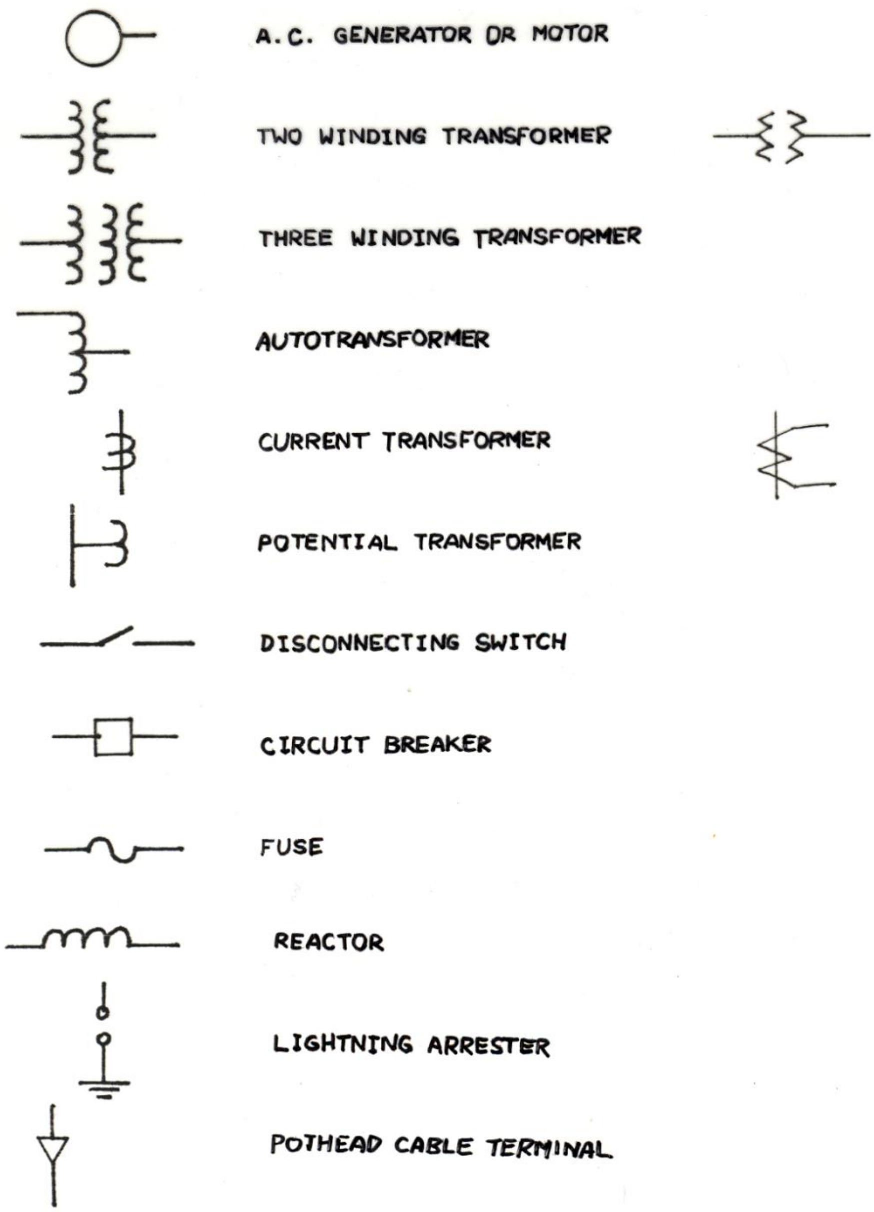
This is an older type of regulator used in the 1920s that uses the principle of a fixed-position field coil and a second field coil that can be rotated on an axis in parallel with the fixed coil. When the movable coil is positioned perpendicular to the fixed coil, the magnetic forces acting on the movable coil balance each other out and voltage output is unchanged. Rotating the coil in one direction or the other away from the center position will increase or decrease voltage in the secondary movable coil.

This type of regulator can be automated via a servo control mechanism to advance the movable coil position in order to provide voltage increase or decrease. A braking mechanism or high ratio gearing is used to hold the rotating coil in place against the powerful magnetic forces acting on the moving coil.

The overall construction is extremely similar to the design of standard AC dynamo windings, with the primary difference being that the rotor does not spin in this device, and instead is held against spinning so the fields of the rotor and stator can act on each other to increase or decrease the line voltage.

7.2 Concept of Bus

Concept of bus in single line diagrams is essentially the same as the concept of a node in an electrical circuit. Just keep in mind that there is one bus for each phase. Buses are shown in SLDs as short straight lines perpendicular to transmission lines and to lines connecting equipment to the buses. In actual substations, the buses are made of aluminium or copper bars or pipes and can be several meters long. The impedance of buses is very low, practically zero, so electrically the whole bus is at the same potential. Of course, there is line voltage between the buses of the individual phases.



F
igure:7.11 **Graphical Symbols for Single Line Diagrams**

Single line diagrams like in figure 2 are used to illustrate the layout of buses in a substation. The arrangement of figure two is called a “breaker and a half”. There are three breakers for every two connections of lines or transformers to the bus, i.e. 1 ½ breakers per termination.

Figure 3 shows a small power system. Any information that is required is added to the SLD. In this case connections of generator and transformer windings, as well as the method of grounding the neutral are indicated. This type of SLD has often also specified the size of the equipment in MVAs, voltage levels, and any other relevant information. (see figure 4)

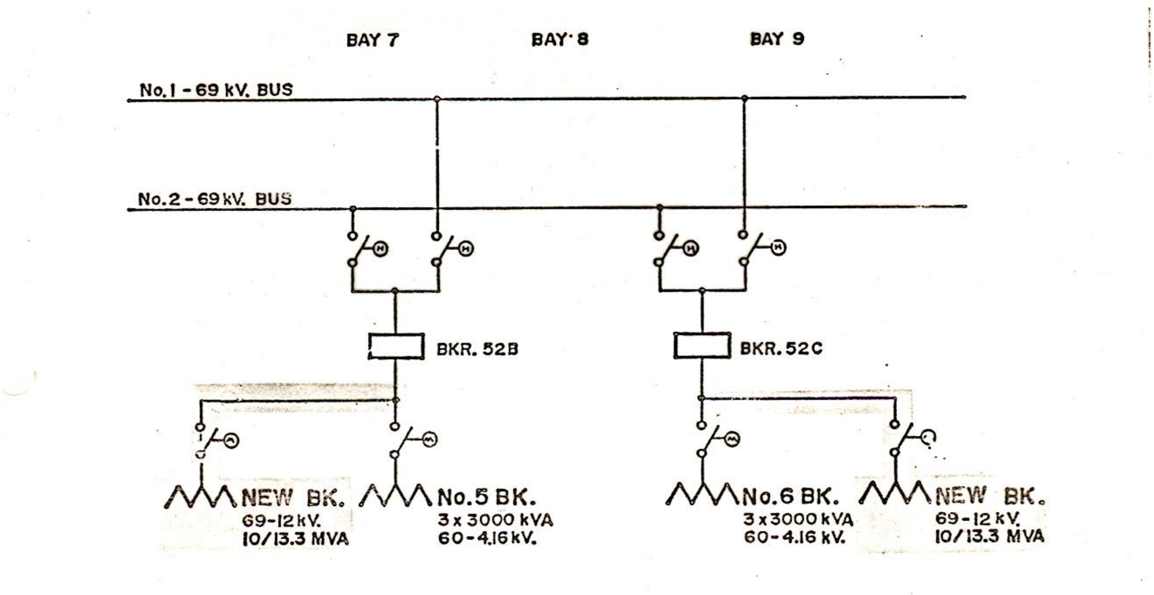


Figure 7.12 Single Line Diagram of a 69 kV/12 kV/4.16 kV Substation

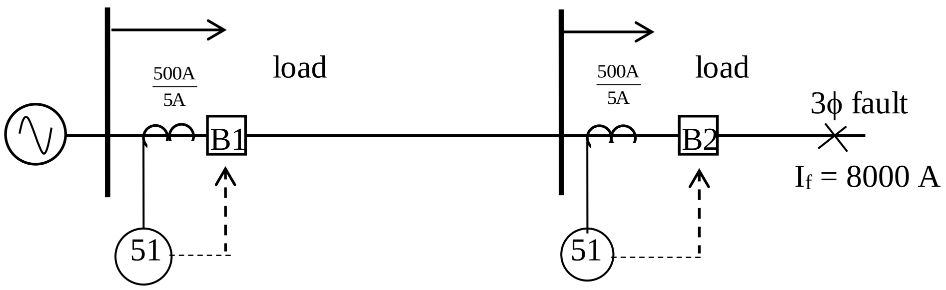


Figure 8.5 Single Line Diagram of over current Protection of a Radial System

Figure 5 shows a radial system of two lines. The buses represent two distribution stations. The outgoing lines have breakers only on the supply end. There are current transformers on the supply end of each breaker. The current transformers are connected to over current relays. Dashed lines between the relays and the breakers indicate a functional relationship; in this case operation of over current relays causes the associated breaker to trip. This type of SLD is used for calculation of fault current and setting and coordination of the relays.

8.3 SINGLE LINE DIAGRAM OF 1X1600KVA & 1X2000KVA 11/0.415KV S/S OF EXTENSION TERMINAL BUILDING FOR CAAB OF KURMITLA,DHAKA.

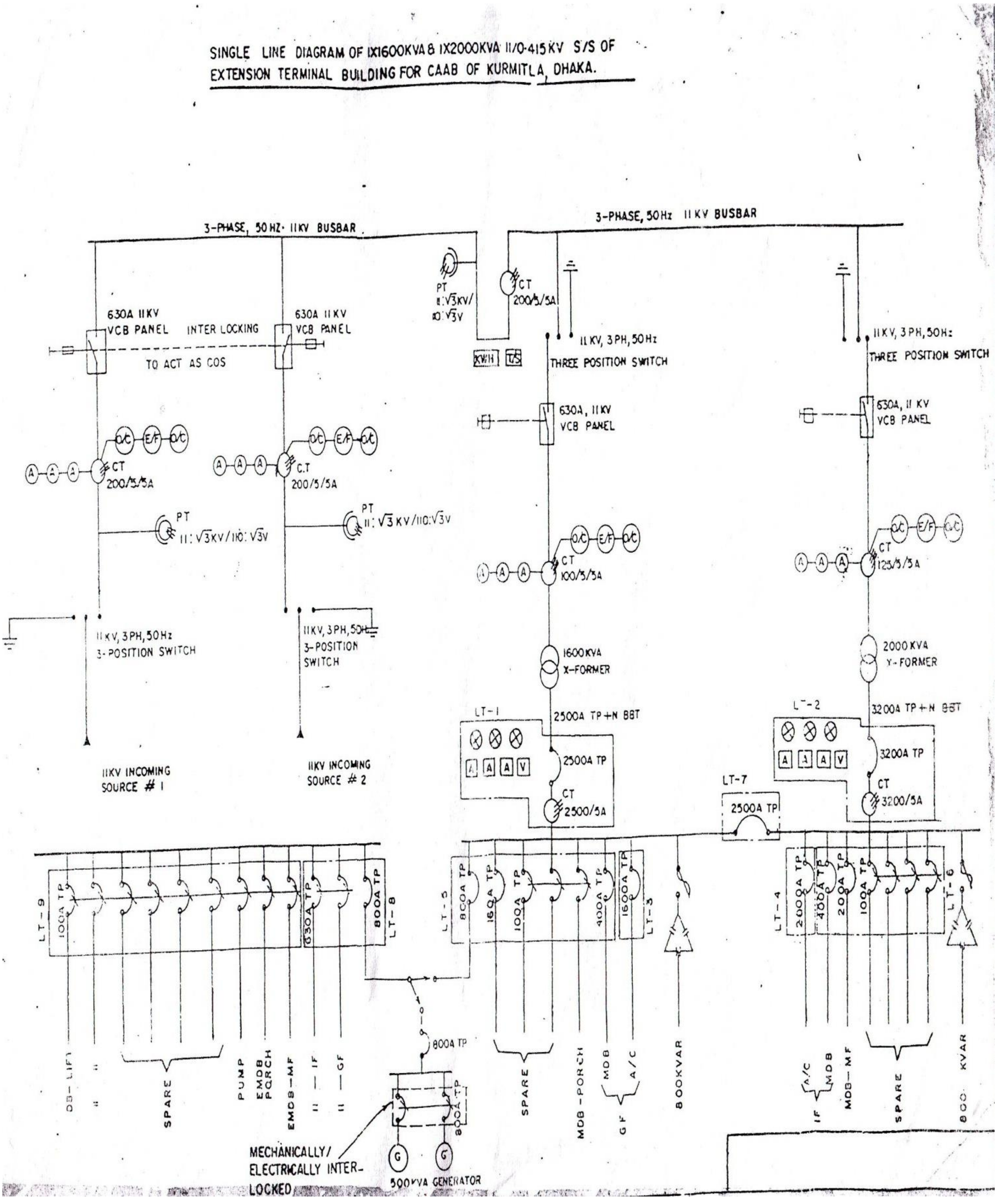


Figure 8.6 SINGLE LINE DIAGRAM OF 1X1600KVA & 1X2000KVA 11/0.415KV S/S OF EXTENSION TERMINAL BUILDING FOR CAAB OF KURMITLA,DHAKA.

Chapter 8

Alternator Protection

Introduction

The generating units, especially the larger ones, are relatively few in number and higher in individual cost than most other equipments.
Therefore, it is desirable and necessary to provide Protection to cover the wide range of faults which may occur in the modem generating plant.

8.1 Different faults

Some of the important faults which may occur on an alternator are
(i) Failure of prime-mover
(ii) Failure of field
(iii) Over current
(iv) Over speed
(v) Over voltage
(vi) Unbalanced loading
(vii) Stator winding faults

(i) **Failure of prime-mover.**

When input to the prime-mover fails, the alternator runs as a synchronous motor and draws some current from the supply system. This motoring condition is known as "inverted running".

(a)In case of turbo-alternator sets, failure of steam, supply may cause inverted running. if the steam supply is gradually restored, the alternator will pick up load without disturbing the system. If the steam failure is likely to be prolonged, the machine can be safely isolated by the control room attendant since this condition is relatively harmless. Therefore, automatic protection is not required.

*(b)*In case of hydro-generator sets, protection against inverted running is achieved by providing mechanical devices on the water-wheel. When the water flow drops to an insufficient rate to maintain the electrical output, the alternator is disconnected from the system, Therefore, in this case also electrical protection is not necessary

(c)Diesel engine driven alternators, when running inverted, draw a considerable amount of power from the supply system and it is a usual practice to provide protection against motoring in order to avoid damage due to possible mechanical seizure. This is achieved by applying reverse power relays to the alternators which *isolate the latter during their motoring action. It is essential that the reverse power relays have time-delay in operation in order to prevent inadvertent tripping during system disturbances caused by faulty synchronizing and phase swinging.

(ii)Failure of field :

The chances of field failure of alternators are undoubtedly very rare. Even if it does occur, no immediate damage will be caused by permitting the alternator to run without a field for a short-period. It is sufficient to rely on the control room attendant to disconnect the faulty alternator manually from the system bus-bars. Therefore, it is a universal practice not to provide automatic protection against this contingency.

(iii) **Over current**

It occurs mainly due to partial breakdown of winding insulation or due to overload on the supply system. Over current protection for alternators is considered unnecessary because of the following reasons:

(a)The modem tendency is to design alternators with very high values 6i internal impedance so that they will stand a complete short-circuit at their terminals for sufficient time without serious overheating. On the occurrence of an overload, the alternators can be disconnected manually.

*(b)*The disadvantage of using overload protection for alternators is that such a protection might disconnect the alternators from the power plant bus on account of some morne.1tary troubles outside the plant and. therefore, interfere with the continuity of elect service.

(iv) **Over speed**

The chief cause of over speed is the sudden loss of all or the major part of load on the alternator. Modern alternators are usually provided with mechanical centrifugal devices mounted on their driving shafts to trip the in dangerous over speed occurs.

(v) **Over-voltage**.

The field excitation system of modem alternators is so designed that over voltage conditions at normal running speeds can1not occur. However, over voltage in an alternator occurs when speed of the prime-mover increases due to sudden loss of the alternator load.

In case of steam-turbine driven alternators, the control governors are very sensitive to speed variations. They exercise a continuous check on over speed and thus prevent the occurrence of over voltage on the generating unit. Therefore, over-voltage protection is not provided on turbo- alternator sets.

In case of hydro-generator, the control governors are much less sensitive and an appreciable time may elapse before the rise in speed due to loss of IoCad is checked. The over-voltage during this time may reach a value which would over-stress the star windings and insulation breakdown may occur. It is, therefore, a usual practice to provide over-voltage protection on hydro-generator units. The over-.voltage relays are operated from a voltage supply derived from the generator terminals. The relays are so arranged that when the generated voltage rises 20% above the normal value, they operate to

(a) trip the main circuit breaker to disconnect **the faulty alternator from** the system

(b) disconnect the alternator field circuit

(vi) **Unbalanced loading.**

Unbalanced loading means that there are different phase current in the alternator. Unbalanced loading arises from faults to earth or faults between phases on the circuit external to the alternator. The unbalanced currents, if allowed to persist, may either severely bum the mechanical fixings of the rotor core or damage the field winding.

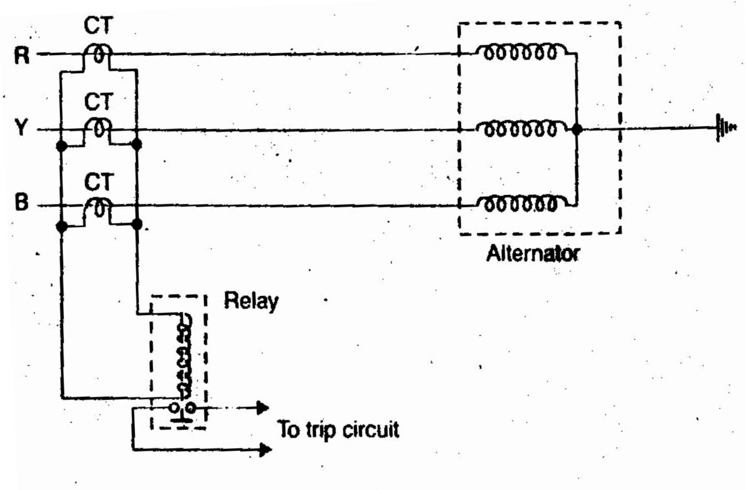


Fig. 22.1

Fig. 22.1 shows the schematic arrangement for the protection of alternator against unbalanced loading. The scheme comprises three line current transformers, one mounted in each phase, having their secondary connected in parallel. A relay is connected in parallel across the transformer secondary. Under normal operating conditions, equal currents flow through the different phases of the alternator and their algebraic sum is zero. Therefore, the sum of the currents flowing in the secondary is also zero and no current flows through the operating coil of the relay. However, if unbalancing occurs, the currents induced in the secondary will be different and the resultant of these currents will flow through the relay. The operation of the relay will trip the circuit breaker to disconnect the alternator from the **system**

(vii)Stator winding faults.

These faults occur mainly due to the insulati on failure of the statorwindings.
The main types of stator winding faults, in order of importance are:
(a) Fault between phase and ground
(b) Fault between phases
(c) Inter turn fault involving turns of the same phase winding

The stator winding faults are the most dangerous and are likely to cause considerable damage to the expensive machinery. Therefore, automatic protection is absolutely necessary to clear such faults in the quickest possible time in order to minimize the *extent of damage. For protection *Of* alternators against such faults, differential method of protection (also knows as Merz-Price system) is most commonly employed due to its greater sensitivity and reliability. This system of protection is discussed in the following section.

8.2 Differential Protection of Alternators

The most common system used for the protection of stator winding faults employs circulating current principle (Refer back to Art. 21.18). In this scheme of protection, currents at the two ends of the protected section are compared. Under normal operating conditions, these currents are equal but may become unequal on the occurrence of a fault in the protected section. The difference of the currents under fault conditions is arranged to pass through the operating coil of the relay. The relay then closes its contacts to isolate protected section from the system. This form of protection is also known as *Herz-Price circulating current scheme.*

8.2.1Schematic arrangement.

Fig. shows the schematic arrangement of current differential protection for a 3-phase alternator. Identical current transformer pairs CT, and CT2 are placed on either side of each phase of the stator windings. The secondary's of each set of current transformers are connected in star ; the two neutral points and the corresponding terminals of the two star groups being connected together by means of a four-core pilot cable. Thus there is an independent path for the currents circulating in each pair bf current transformers and the corresponding pilot P.

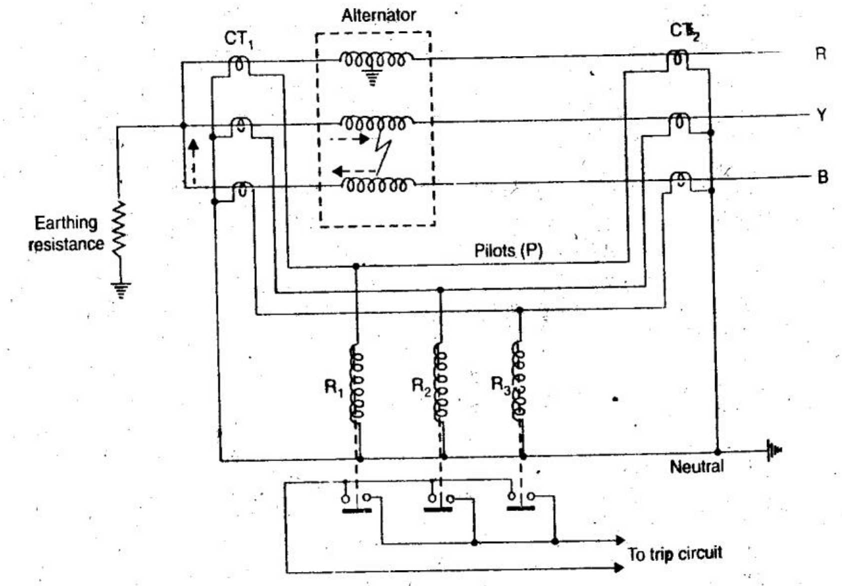


Fig. 22.2

The relay coils are connected in star, the neutral point being connected to the current transformer common neutral and the outer ends one to each of the other three pilots. In order that burden on each current transformer is the same, the relay-, are connect6d across equi potential points of the three pilot wires and these equi potential points would naturally be located at the middle of the pilot wires. The relays are generally of electromagnetic type and are arranged for instantaneous action since fault should be cleared as quickly as possible.

8.2.2Operation.

Referring to Fig. 22.2, it is clear that the relays are connected in shunt across each circulating path. Therefore, the circuit of Fig. 22.2 can be shown in a simpler form in Fig. 22.3. Under normal operating conditions, the current at both ends of each winding will be equal and hence the currents in the secondary of two CTs connected in any phase will also be equal. Therefore, there is balanced circulating current in the pilot wires and no current flows through the operating coils *(R,, R2* and *R,)of* the relays. When earth fault or phase to phase fault occurs, this condition no longer holds good and the differential current flowing through the relay circuit operates the relay to trip the circuit breaker.

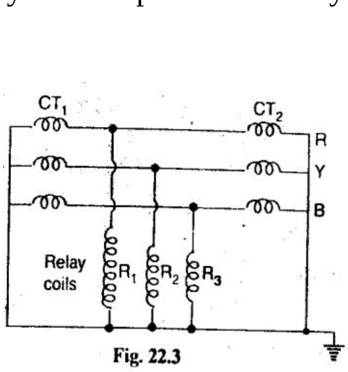


Fig. 22.3

(i)Suppose an earth fault occurs on phase *R* due to breakdown of its insulation to earth as shown in Fig. 22.2. The current in the affected phase winding will flow through the core and frame of the machine to earth, the circuit being completed through the neutral earthing resistance. The currents in the secondary's *of* the two CTs in phase *R will* become unequal and the difference of the two currents will flow through the corresponding relay coil *(i.e R,),* returning via the neutral pilot. Consequently, the relay operates to trip the circuit breaker.

(ii) Imagine that now a short-circuit fault occurs between the phases Y and B as shown in Fig. 22,2. The short-circuit current circulates via the neutral end connection through the two windings and through the fault as shown by the dotted arrows. The currents in the secondaries of two CTs in qach affected phase will become unequal and the differential current will flow through the operating coils of the relays *(i.e.* R2 and *R)* Connected in these phases. The relay then closes its contacts to trip the circuit breaker.

It may be noted that the relay circuit is so arranged that its energizing causes (i) opening of the breaker connecting the alternator to the bus-bars and (ii) opening of the *field circuit of the alternator.

It is a prevailing practice to mount current transformers CT, in the neutral connections (usually in the alternator pit) and current transformers CT2 in the switch-gear equipment. In some cases, the alternator is located at a considerable distance from the switchgear. As the relays are located close to th e circuit breaker, therefore, it is not convenient to connect the relay coils to the actual physical midpoints of the pilots. Under these circumstances, balancing resistances are inserted in the shorter lengths of the pilots so that the relay tapping points divide the whole secondary impedance of two sets of CTs into equal portions, This arrangement is shown in Fig. 22.4. These I resistances are usually adjustable in order to obtain the exact balance.

Limitations. The two circuits for alternator protection shown above have their own limitations. It is a general practice to use neutral farthing resistance in order to limit the destructive effects of earth7fault currents. In such a situation, it is impossible to protect whole of the stator windings of a star connected alternator during earth faults. When an earth fault occurs near the neutral point, there

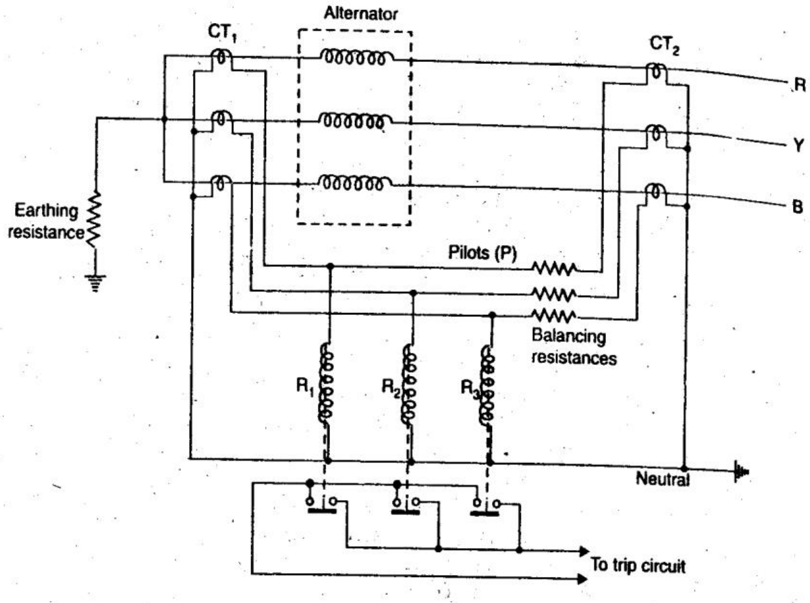


Fig. 22.4

may be insufficient voltage across the short-circuited portion to drive the necessary current round the fault circuit to operate the relay. The magnitude of unprotected zone depends upon the value of earthing resistance and relay setting.

Makers of protective gear speak of "protecting 80% of the winding" which means, that faults in the 20% of the winding near the neutral point cannot cause tripping i.e. this portion is unprotected. It is a usual practice to protect only 85% of the winding because the chances of an earth fault occurring near the neutral point are very rate due to the uniform insulation of the winding throughout.

8.3 Modified Differential Protection for Alternators

If the neutral point of a star-c6nnected alternator is earthed through a high resistance, protection schemes shown in Fig. 22.2 or 22.4 will not provide sufficient sensitivity for earth-faults. It is be cause the high earthing resistance will limit the earth-fault currents to a low value, necessitating relays with low current settings if adequate portion of the generator winding is to be protected. However, too low a relay setting is undesirable for reliable stability on heavy through phase faults. In order-10 overcome this difficulty, a mod ' ified form of differential protection is used in which the setting Of earth faults is reduced without impairing stability.

The modified arrangement is shown in Fig. 22.5. The modifications affect only the relay connections and consist in connecting two relays for phase fault protection and the third for earth fault protection only. The two phase elements (PC and PA) and balancing resistance (BR) are connected in star and the earth relay (ER) is connected between **this** star point and the fourth wire of circulating current pilot circuit.

8.3.1 Operation.

Under normal operating conditions, currents at the' two ends of each stator winding will be equal. Therefore, there is a balanced circulating current in the phase pilot wires and no **current flows through the operating coils of the relays. Consequently, the relays remain** inoperative.

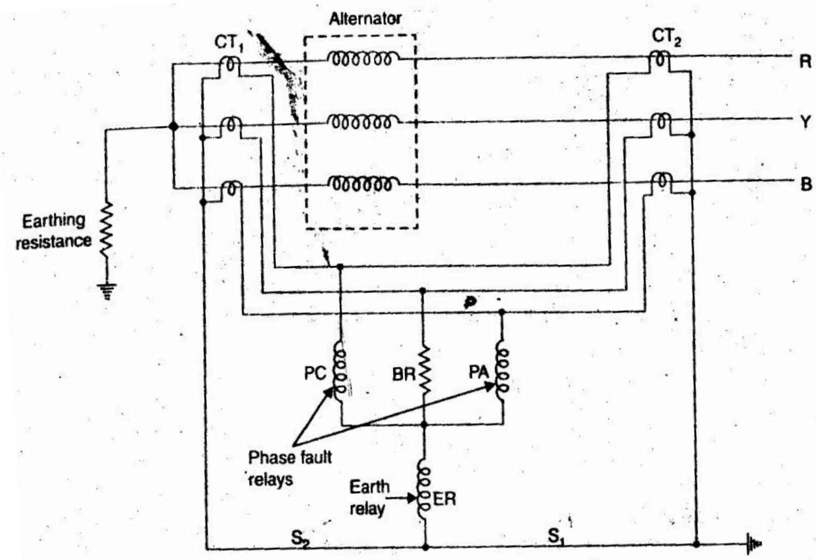


Fig. 22.5

If an earth fault occurs on any one phase,the out of thfe balance secondary current in CTs in that phase will flow through the earth relay only.If a fault occurs between two phases, the out of the balanced currents will circulate round the two transformer secondaries via any two of the coils PA,*BR*, *PC* (the pair being decided by the two phases that are faulty) without passing through the earth relay *ER.* Therefore, only the phase fault relays will operate.

8.4 Balanced Earth fault Protection

,In small size alternators, the neutral ends of the three phase windings are often connected internally' to a single terminal. Therefore, it is not possible to use Merz - Price circulating current principle described above because there are no facilities for accommodating the necessary current transformers in the neutral connection of each phase winding. Under these circumstances, it is considered sufficient to provide protection against earth - faults only by the use of balanced earth' fault protection scheme. This scheme provides no protection against phase – to - phase faults, unless and until they develop into earth faults, as most of them will.

8.4.1 Schematic arrangement.

Fig. 22.6 shows the schematic arrangement of a balanced earth fault Protection fora 3-phase alternator. It consists of three line current transformers, one mounted in each phase, having their secondary's connected in parallel with that of a single current transformer in the conductor joining the star point of the alternator to earth. A relay is connected across the transform is secondary's. The protection against earth faults is limited to the region between the neutral and the line current transformers.

8.4.2Operation.

Under normal operating conditions, the currents flowing in the alternator leads and hence the currents flowing in secondary's of the line current transformers add to zero and no current flows through the relay. Also under these conditions, the current in the neutral wir~ is zero and the secondary of neutral current transformer supplies no current to the relay.

If an earth fault develops at F, external to the protected zone, the sum of the currents at the terminals of the alternator is exactly equal to the current in the neutral connection and hence no

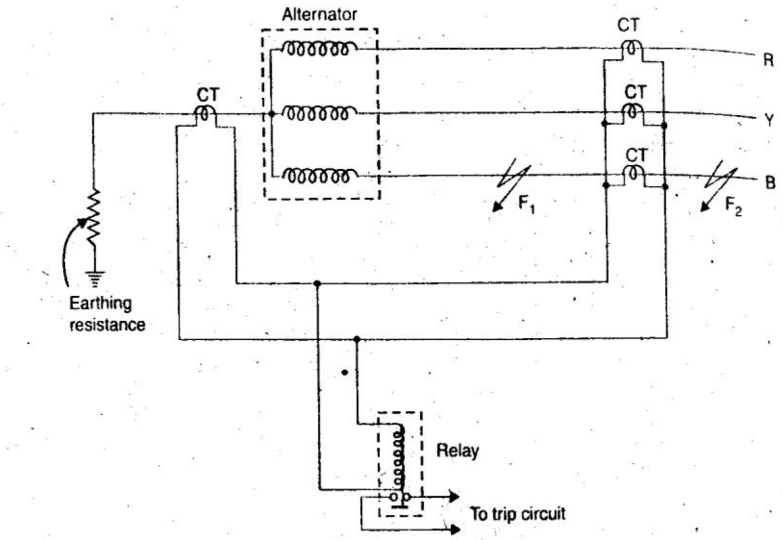


Fig. 22.6

current flows through the relay. When an earth fault occurs at F, or within the protected zone, these currents are no longer equal and differential current flows through the operating coil of the relay. The relay then closes its contacts to disconnect the alternator from the system.

8.5 Stator Inter turn Protection

Merz-price circulating-current system protects against phase-to-ground and phase-to-phase faults. It does not protect against turn-to-tum fault on the same phase winding of the stator. It is because the current that this type of fault produces flows in a local circuit between the turns involved and 4pes not create a difference between the currents entering and leaving the winding at its two ends where current transformers are applied. However, it is usually considered unnecessary to provide protection for inter-tum faults because they invariably develop 'into earth-faults.

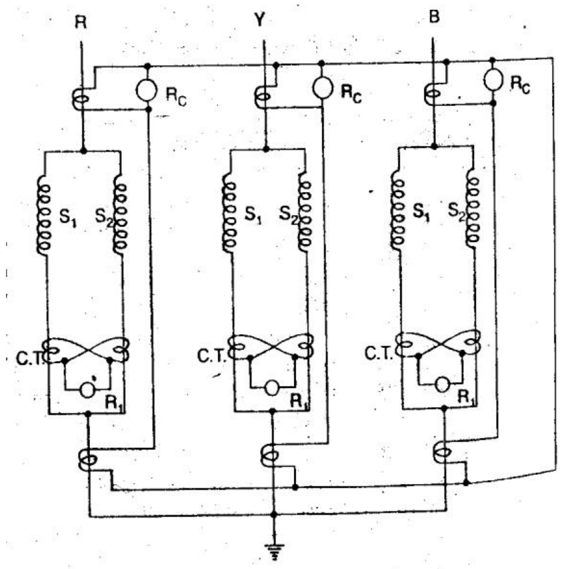


Fig. 22.7

In single turn generator (e.g. large steam turbine generators), there is no necessity of protection against inter-turn faults. However, inter-tum protection is provided for multi-turn generators such as hydro-electric generators. These generators have double winding ,armatures owing to the very heavy currents which they have to carry. Advantage may be taken of this necessity to protect interterm faults on the same winding. Fig. 22.7 shows the schematic arrangement of circulating current and interterm protection of a 3-phase double wound generator. The relays *Rc* provide protection against phase to ground and phase to phase faults whereas relays *R,* provide protection against inter-tum faults.

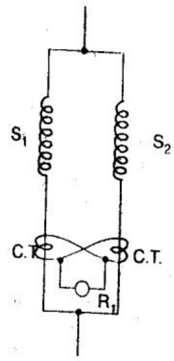


Fig. 22.8

Fig. 22.8 shows the duplicate stator windings S, and S, of one phase only with a provision against interterm faults. Two current transformers are connected on the circulating current principle. Under normal conditions, the currents in the stator windings S, and S, are equal and so will be the currents in the secondary's of the two CTS. The secondary current round the loop then is the same at all points and no current flows through the relay *R,* If a short-circuit develops between adjacent turns, say on Sp the currents in the stator windings S, and S,
will no longer he equal. Therefore, unequal currents will be induced in the secondary's of C Is and the difference of these two currents flows through the *relayR1.* the relay then closes its contacts to clear the generator from the system.

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