# Evaluation of the performance of a steam engine as electric generator.

A thesis

by


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Submitted to the

DEPARTMENT OF MECHANICAL ENGINEERING
SONARGAON UNIVERSITY (SU)
In partial fulfillment of the requirements for the award of the degree
Of
Bachelor of Science in Mechanical Engineering

September 2022

**Acknowledgement**

First of all, we give thanks to Allah or God. It gives us immense pleasure to express our deep sense of gratitude to **Md. Suzauddin, Lecturer Sonargaon University, Dhaka, Bangladesh,** our guide and supervisor for his invaluable guidance, motivation and constant inspiration. He always bestowed parental care upon us and evinced keen interest in solving our problems. An erudite teacher, a magnificent person and a strict disciplinarian, we consider ourselves fortunate to have worked under his supervision. We are extremely thankful to **Md. Mostofa Hossain, Head and Department of Mechanical Engineering, Sonargaon University, Dhaka, Bangladesh,** for their help and advice during the course of this work. We are greatly thankful to all the staff members of the department and all our well-wishers, classmates and friends for their inspiration and help. Finally, Authors also want to give cordial thanks to those teachers who have helped for this project work directly or indirectly to complete it.

## Abstract

The first recorded rudimentary steam engine was the aeolipile described by Heron of Alexandria in 1st-century Roman Egypt. Several steam-powered devices were later experimented with or proposed, such as Taqi al-Din's steam jack, a steam turbine in 16th-century Ottoman Egypt, and Thomas Savory's steam pump in 17th-century England. In 1712, Thomas Newcomer's atmospheric engine became the first commercially successful engine using the principle of the piston and cylinder, which was the fundamental type of steam engine used until the early 20th century. The steam engine was used to pump water out of coal mines.

During the Industrial Revolution, steam engines started to replace water and windpower, and eventually became the dominant source of power in the late 19th century and remaining so into the early decades of the 20th century, when the more efficient steam turbine and the internal combustion engine resulted in the rapid replacement of the steam engines. The steam turbine has become the most common method by which electrical power generators are driven. Investigations are being made into the practicalities of reviving the reciprocating steam engine as the basis for the new wave of advanced steam technology.



**Key Points:** Steam boiler, Generate Electricity, Power

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## Chapter 1

# Introduction

### 1.1 Introduction:

Steam engines are external combustion engines, where the working fluid is separate from the combustion products. It performs mechanical work by using steam as its working fluid. In 1781 James Watt patented a steam engine that produced continuous relative motion. Watt's ten-horse power engines enabled a wide range of manufacturing machinery to be powered. The engines could be sited anywhere that water and coal or wood fuel could be obtained. By 1883,engines that could provide 10,000 HP had become feasible. Steam engines could also be applied to vehicles such as traction engines and the railway locomotives. The stationary steam engine was a key component of the Industrial Revolution, allowing factories to locate where water power was unavailable. Although the reciprocating steam engine is no longer in widespread commercial use, various companies are exploring or exploiting the potential of the engine as an alternative to internal combustion engines. The company Energiprojekt AB in Sweden has made progressin using modern materials for harnessing the power of steam. Theefficiency of Energiprojekt's steam engine reaches some 27-30% onhigh-pressure engines. It is a single-step, 5-cylinder engine (no compound) with superheated steam and consumes approx. 4 kg (8.8 lb.) of steam per kWh.

**1.1.1 Steam Power Plant:** It is the power plant which is used to generate electricity by the use of steam turbine. The major components of these power plants are boiler, steam turbine, condenser, and water feed pump.

The site selection of steam power plant depends upon various factors. Let’s discuss these factors one by one

**1.1.2 Cost of the land:** The cost of the land which is selected for the installation should be minimum or economical.

**1.1.3 Population density of the land:** The distance of the steam power plant from the public area should be at appropriate distance. So that in case of any failure or hazard happen in the plant, the population of the area near to the power plant should not be affected.

**1.1.4 Availability of water sources:** There should be a plenty of water sources in the selected area. Since the power plant requires a large amount of water for the generation of steam.

**1.1.5 Availability of fuel**: The availability of required fuel (coal) should be there because without fuel the plant will not work.

**1.1.6 Type of land:** The land which is selected for the power plant installation should be plain enough and it is suitable for the strong foundation for the various machinery of the plant.

**1.1.7 Scope for the future demand:** The size of the land should be such that it is capable for the handling of future power demand.

**1.1.8 Availability of Ash handling facility:** Proper ash handling facility should be available near the power plant to minimize the adverse effect of the ash produced in the steam power plant

**1.1.9 Availability of transportation facility:** The transportation facility is must in the installation for the power plant, because any material cannot be transported to the power plant form its required location in lack of transport. There should be easy availability of proper transportation facility at the selected site.

## 1.2. Objectives:

- To generate electricity from Steam Engine.
- To Turn thermal energy into another form of energy, mostly electricity.
- To operate electrical device by generate device by generating electric power from Steam Engine.

**Chapter 2**

# Methodology & Literature Review

## 2.1 Introduction:

The steam power plant is an important source to produce the electricity. The major portion of electricity demand is fulfilled by this power plant. It is also called a thermal power plant. It provides the electricity required to different areas. In this article we will study the construction, working, efficiency, advantages, and disadvantages of steam power plants.

A steam turbine can be defined as a form of heat engine in which the energy of the steam is transformed into kinetic energy by expansion through nozzles, and the kinetic energy of resulting jet is in turn converted into force on rings of blades mounted on a rotating disc. Steam micro-turbines are considered to be such devices which produce output power of the order of a few kWs. Steam turbines on micro-power plants are capable of delivering electric power ranging 1 - 6 kW [1]. For optimal electricity production, a thermal power plant (TPP) is chosen to encompass effective and robust choice of facilities. The turbine and the alternator are facilities of importance in the constitution of a TPP. The ability of turbine to generate a rotary motion made it suitable to drive an electrical generator. In the search for an alternative source of energy, palm kernel shell was found to be a well-known biomass product because of its higher heat energy or calorific value. Palm kernel shell has gained it status as a biofuel resource for biomass product which is cheap, readily available and due to its high calorific value, its properties can be utilized in creation of an efficient micro-power plant which comprises of five main components which are the boiler, turbine, generator, condenser and pump. It is therefore beneficial to produce high pressure steam, and let it expand to the desired pressure and temperature through a turbine or to extract part of the steam from the turbine before it reaches the low-pressure stage and its rotary motion is used to drive the generator to produce electricity. The aim of this research is to conduct a design analysis for an efficient steam turbine for a palm kernel shell (PKS) fuelled micro power plant which will generate 5 kW electricity. The specific objectives of this research are to: design and analyze a steam turbine based on predetermined design considerations and materials selection criteria; and evaluate the performance of the steam turbine in propelling the generator to produce 5 kW of electricity. The design analysis has formed a baseline for the development of a steam turbine with target of producing 5 kW of electricity in micro power plant using PKS as fuel. The research is limited to design, simulation and analysis of the rotor, blades and nozzle of the steam turbine. Palm kernel shell (PKS) is the main by-product of palm kernel oil production. Palm kernel is kernel from oil palm fruit. After the oil palm fruit went through the palm oil process, the kernels are separated and kernel oils distilled. Oladosu and Oladosu et al. optimized the combustion of palm kernel shell (PKS) in a grate furnace for superheated steam generation. The outcome supported the use of PKS for power generation because of its higher heating value, but the study failed to implement same. Oladosu et al. used computer based approach to design palm kernel shell combusting furnace for generating a desired amount of electricity. By way of backward calculation approach, standard design equations were used to size furnace, Turbine and other components. The results showed that to system. This is the area this study attempted to address. Chandra et al. analyzed the behavior of rotors on different mechanical and thermal-mechanical analyses to find out the better one out of the solid rotor and the hollow rotor in terms of ease of manufacturing and failure. Further analysis based on thermal and structural distribution on blades was carried out. This study is deficient by not taking a step ahead in analyzing critical turbining parameters, which are stress/load, torsion/strain, temperature, and speed tolerance. Chenduran analyzed, in blade design, stress failures, efficiency and nozzle angle using solid works software. Many designs have been carried out on turbines ranging from single-stage axial-flow turbines, two-stage axial-flow turbines, radial-flow turbines to radial-axial-flow turbines, efforts in the area of micro-turbine design for micro-power plant have been scanty. This is the germane area in which this study is posed to contribute.

## 2.2 Methods:

In the design of a steam micro-turbine, there are major parameters to be considered. The input parameters included the superheated steam temperature, pressure, mass flow rate and other specific properties. The required output to achieve necessary power supply required are the angular velocity, speed, and torque. Others include the type of cycle for effective conversion, the classification of the steam turbine, the blade profile design and arrangement, the number of stages required for effective steam pressure utilization, nozzle and condenser design. The turbine design process has a series of steps as enumerated in Figure 1. Turbine specifications; these include the rotational speed or speed range, steam pressures at the turbine's inlet and exhaust, steam temperature at the turbine inlet, and the desired power output. Determination of staging based on the turbine specifications; the turbine designer makes some basic decisions on which the flow path design is built, such as degree of reaction, desired blade peripheral speed, stage diameters, and number of stages in the turbine. At this stage, the number of rows of stationary and moving blades is established. Determination of optimum flow passage angles by creating velocity diagrams for each stage based on the mean diameter of the flow path to determine appropriate airfoil entrance and exit angles, for best performance at the design. Detailed stage design determines the quantity and the size (that is the width or chord) of the blades (short constant section airfoils or a series of radial stations for tall blades with twisted airfoil shapes). Reliability evaluation ensures that steady steam bending and centrifugal forces are within acceptable limits. The vibratory characteristics of the blades are predicted and compared with the frequency and shape of unsteady forces from a variety of sources that acted on the blades. Steam turbine depends completely upon the dynamic action of the steam. Working principle of the power in a steam turbine is obtained by the rate of change in momentum of a high velocity jet of steam and hit on a curved blade, which is free to rotate based on the Newton's second law's rate of change of momentum. The blades are attached to the rotor shaft. The resultant of blade forces is converted into shaft power to drive the load. The loading on a rotating turbine blade is composed of centrifugal force due to rotation, bending force due to the fluid pressure and change of momentum. The design specifications by taking cognizance of the designed steam boiler where palm kernel shell was used as heat energy source was applied in this study.

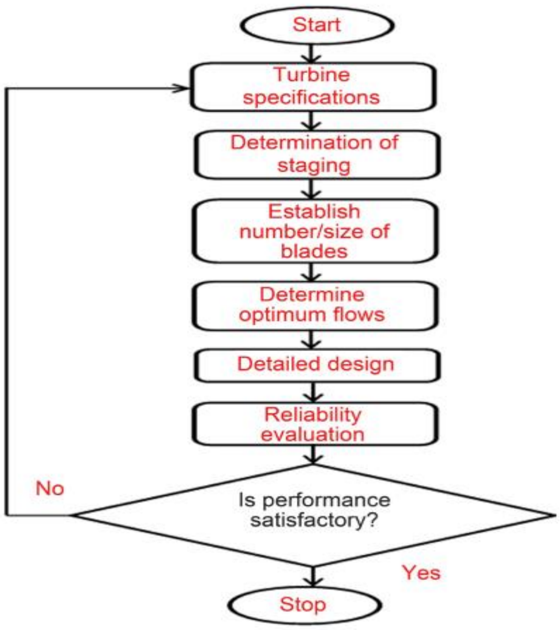



Figure 2.1: Design flow chart for the micro-turbine for 5 kW electricity production.

The specifications can sustain a multistage impulse flow steam micro turbine of power 5.5 kW, steam mass flow rate 0.0275 kg/s, expected efficiency of 75%, inlet temperature 400˚C and speed (greater than 1500 rpm)

## 2.3 Literature Review

A Selecting the right steam turbine and the power generation cycle need some basic parameters such as output power and speed of the turbine. In an Extraction Steam Turbine, steam for the thermal load is obtained by extraction from one or more intermediate stages at the appropriate pressure and temperature. The remaining steam is exhausted to the pressure of the condenser, which can be as low as 0.05 bar with a corresponding condensing temperature of about 33°C. In order to assure optimal electricity production and the best conditions of efficiency and security, a thermal power plant (TPP) is brought to choose an effective and robust choice of facilities.

A cumbersome steam carriage for roads was built in France by Nicholas-Joseph Cugnot as early as 1769. Richard Trevithick in England was the first to use a steam carriage on a railway; in 1803 he built a steam locomotive that in February 1804 made a successful run on a horse car route in Wales. The adaptation of the steam engine to railways became a commercial success with the Rocket of English engineer George Stephenson in 1829. The first practical steamboat was the tug Charlotte Dudes, built by William Symington and tried in the Forth and Clyde Canal, Scotland, in 1802. Robert Fulton applied the steam engine to a passenger boat in the United States in 1807.

Though the steam engine gave way to the internal-combustion engine as a means of vehicle propulsion, interest in it revived in the second half of the 20th century because of increasing air-pollution problems caused by the burning of fossil fuels in internal-combustion engines.

boiler, also called Steam Generator, apparatus designed to convert a liquid to vapour. In a conventional steam power plant, a boiler consists of a furnace in which fuel is burned, surfaces to transmit heat from the combustion products to the water, and a space where steam can form and collect. A conventional boiler has a furnace that burns a fossil fuel or, in some installations, waste fuels. A nuclear reactor can also serve as a source of heat for generating steam under pressure.

Boilers were built as early as the 1st century AD by Hero of Alexandria but were used only as toys. Not until the 17th century was serious consideration given to the potential of steam power for practical work. The first boiler with a safety valve was designed by Denis Pepin of France in 1679; boilers were made and used in England by the turn of the 18th century. Early boilers were made of wrought iron; as the advantages of high pressure and temperature were realized, manufacturers turned to steel. Modern boilers are made of alloy steel to withstand high pressures and extremely high temperatures.

Most conventional steam boilers are classed as either fire-tube or water tube types. In the fire-tube type, the water surrounds the steel tubes through which hot gases from the furnace flow. The steam generated collects above the water level in a cylindrically shaped drum. A safety valve is set to allow escape of steam at pressures above normal operating pressure; this device is necessary on all boilers, because continued addition of heat to water in a closed vessel without means of steam escape results in a rise in pressure and, ultimately, in explosion of the boiler. Fire-tube boilers have the advantage of being easy to install and operate. They are widely used in small installations to heat buildings and to provide power for factory processes. Fire-tube boilers are also used in steam locomotives.

The project as a whole is divided in three major parts namely- Boiler, Turbine and Electricity Tariff.

A. Boiler (Thermax CB 20)

Here, the „Thermax Combloc-20" is considered as a definitive boiler for steam generation. Combloc, the steam boiler offers customers who are forced to choose between a particular boiler design and a solid fuel option, a way out. This versatile fully packaged boiler launched by Thermax Heating SBU combines the fuel flexibility of a hybrid boiler and the inherent ruggedness and compactness of an integral furnace boiler. Combloc provides customers various options for fuel combustion - imported coal, Indian coal, pet coke, wood chips, rice husk, pellets, wood logs, dry biomass, etc. Without making expensive and time consuming boiler modifications industries can switch between these fuels, depending on their cost and availability. Combloc's compact design helps clients avoid the hassles of site civil work, longer installation time and higher investments. In a small foot print, the boiler offers one of the highest thermal efficiencies. This boiler is available in the range of 1.5 to 6 TPH.

**Technical Specifications**: -

- Boiler type - Horizontal Multi-tubular Shell Type Smoke Tube with Water Wall Furnace.
- Max steam output - 2000 kg/hr
- Design Pressure - 10.54/17.5 kg/sq. cm
- Temperature - 185/208 °C
- Dryness - 98%
- Steam / Fuel ratio- 4.55
- Efficiency- 85.5% (for wood)
- Fuel type- wood chips ( 7 to 20 mm)
- Fuel moisture content- 15% to 25%

- Ash content - ≤ 8%
- Net Calorific Value of „Wood Chips‟ - 2950 kcal/kg

B. Micro Steam Turbine (CTMI- PS902C)

The steam turbine considered is manufactured by „Chola Turbo Machinery International Pvt ltd‟. The condensing turbines take high pressure steam, expand it in turbine nozzles and blades, and exhaust it to a condenser at lower than atmospheric pressure. It is principally used when power must be generated with minimum steam consumption [3]. The condensing turbine may also have bleed points (uncontrolled extractions) to satisfy steam demands at medium intermediate pressures. SALIENT FEATURES OF PS 902C

- Condensing Single Stage Steam Turbine
- Woodward TG-13 oil relay governor
- Positive over speed trip
- Antifriction ball bearings throttle valve
- Ball thrust with minimum 48,000 L10 rating
- Horizontally split case with metal to metal joint for ease of maintenance
- Multiple carbon ring gland seals with stainless steel spacers
- Foot mounted support system Large bearing housing with constant level oilers and integral cooling water jackets
- Wheel with stainless steel blades
- Large efficient monel nozzles
- Balanced, cage guided throttle valve
- Stainless steel turbine shaft
- Simplicity of design assures reliability and low maintenance
- Positive seating tight shutoff valve
- Stainless steel strainer
- Sentinel warning valve
- Optional exhaust location

**Technical Specifications:-**

- Maximum Inlet Gauge Pressure (PSI/Bar)- 640/45
- Maximum Inlet Temperature (°F/°C)- 840/450
- Maximum Exhaust Gauge Pressure (PSI/Bar)- 150/10
- Speed Range (RPM)- 1000-5000
- Overall Efficiency - 59.29%
- Bearing Type- Ball and/or sleeve
- Wheel Pitch Diameter (IN/mm)- 17.7450
- Approx. Maximum Rating (HP/KW)- 405/300
- Approx. Shipping Weight (LB/kg)- 1100/500
- API 611 compliant

C. Tariff

The utility company for providing electricity to the consumers is MSEDCL. The following category is considered for further calculations. HT II (A): EXPRESS FEEDERS Applicability - Applicable for use of electricity / power supply at High Tension on Express Feeders in all non-residential, nonindustrial premises and/or commercial premises for commercial consumption meant for operating various appliances used for purposes such as lighting, heating, cooling, cooking, washing/cleaning, entertainment/leisure, pumping in following (but not limited to) places :

- Non-Residential, Commercial and Business premises, including Shopping Malls / Show Rooms
- Film Studios, Cinemas and Theatres including Multiplexes, Hospitality, Leisure, Meeting / Town Halls and Places of Recreation & Public Entertainment
- Marriage Halls, Hotels / Restaurants, Guest Houses, Internet / Cyber Cafes, Mobile Towers, Microwave Towers, Satellite Antennas used for telecommunication activity, Telephone Booths, Fax / Xerox Shops
- Automobile, Any Other Type of Workshops, Petrol Pumps & Service Stations including Garages, Tyre Re-treading / Vulcanizing units
- Sports Club, Health Club, Gymnasium, Swimming Pool

**Chapter 3**

# Hardware Implementation

## 3.1 Introduction:

The steam to design our proposed system we need to collect some instruments and all the parts are added in this chapter and describe broadly.

Steam was the energy that powered the early industrial revolution. Steam pistons drove factories. Steam turbines were and still are, responsible for generating most of the world's electricity. A number of steam powered projects are good for demonstrating physics principles and engineering principles. The first step to creating a steam powered machine is to make a steam generator.

Water Tank

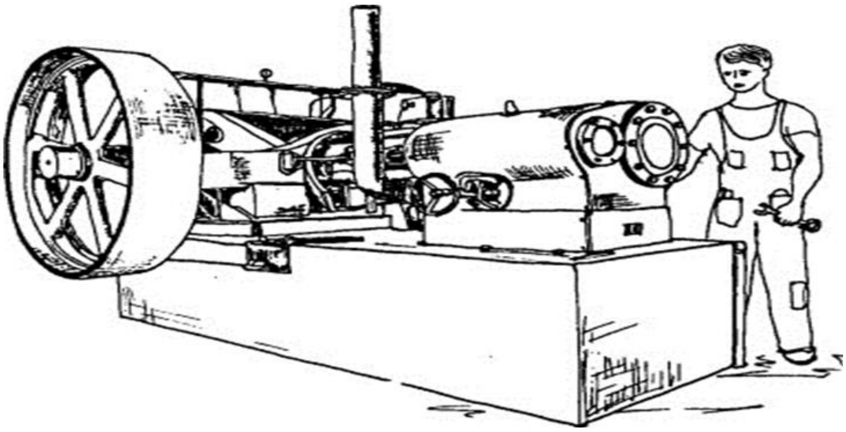
The exact tank design will depend on the power source you will use. If you are going to use an immersion heater, fashion a bracket to suspend the immersion heater in the water tank. A good water tank can be made form an empty grapefruit juice can. Cut the top out of the can and make holes for the immersion heater elements so the electrical component will not be inside the tank. Solder the top of the can in place with the immersion heater protruding through the top. Seal the area of the lid where the immersion heater protrudes. Good, high heat tape is a good start, but clay may be necessary for better steam pressure. If you use clay, make sure you allow the clay to harden and cure.

Water Inlet & Steam Outlet

Install a re-sealable plumbing fixture on the can. This will serve as a fill point for the tank. Drill a hole for a small metal tube. Fish tank air connectors work well. Solder a small steel pipe through this hole. Using flexible pipe will allow the steam to be routed to something like a piston or a turbine.

## 3.2 Basic Components of Steam Engine:

**3.2.1 Frame/Base Plate**: Frame/Base Plate is the structure that forms the backbone of the railway locomotive, giving it strength and supporting the superstructure elements such as a cab, boiler or bodywork. The vast majority of locomotives have had a frame/Base Plate structure of some kind. The frame/Base Plate may in turn be supported by axles directly attached to it, or it may be mounted on bogies (UK) / trucks (US), or a combination of the two. The bogies in turn will have frames/Base Plate of their own.



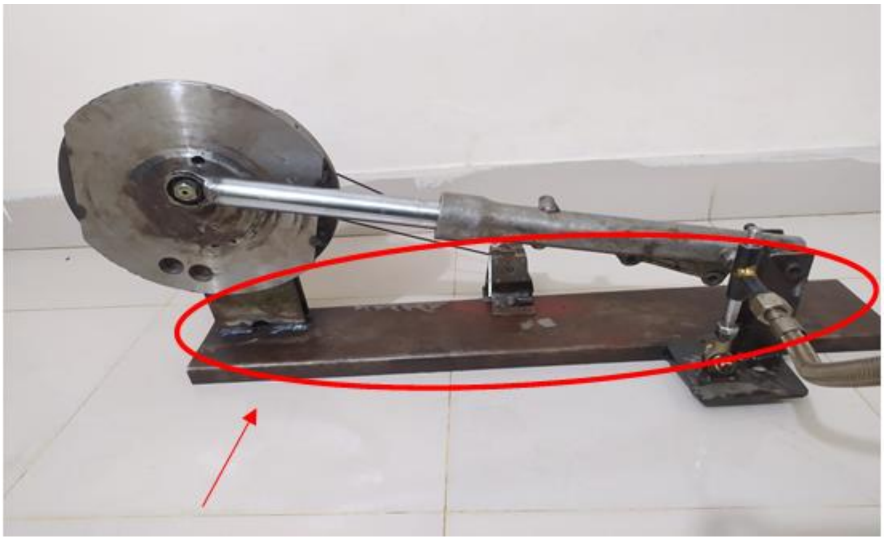


Figure3.1: Steam engine frame/base plate

**3.2.2 Steam Chest:** Steam-chest is a chamber that encloses the slide valve of a steam engine and forms a manifold for the steam supply to the valve. The steam chest is the "reservoir" for collection of steam as it passes between the super heater header and the inlet port to the cylinder. The steam chest (or steam chest) is the "reservoir" for collection of steam as it passes between the superheater header and the inlet port to the cylinder.

The advantage of a large steam chest (as is the advantage of any reservoir) is that functions in pressure as the steam passes from the steam chest into the cylinder are reduced. The higher the steam chest pressure, the greater the quantity of steam that can be delivered to the cylinder while the inlet port is open, and the higher the cylinder pressure at the point of cut-off. Maximizing cylinder pressure at the point of cut-off serves to maximize the work done by the steam on the piston. In alternative words, it serves to maximize the area within the indicator diagram.

Ideally, the steam chest volume should equal (or exceed) the cylinder volume, but never came near this in FGS locomotives. One of the modifications that Wardle made in developing The Red Devil was enlargement of the steam chests which are easily visible on the photo below. In fact, the extent of the enlargement was limited by other constraints such that their volume increased only from 33.2% of cylinder volume to just 35.5% compared to an ideal minimum of 100%. By contrast, the 5AT steam chest volume is almost exactly 100% – see line [158] of FDC 6.

Figure3.2: Steam Chest

**3.2.3 Boiler:** The high-pressure steam for a steam engine comes from a boiler. The boiler's job is to apply heat to water to create steam. There are two approaches: fire tube and water tube.

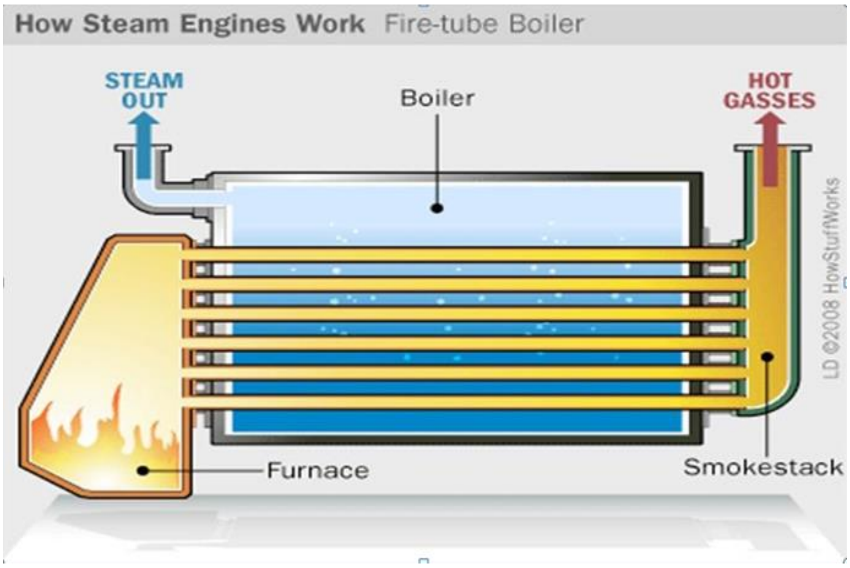



Figure3.3: Boiler of steam engine

**3.2.4 Slide valve:** The slide valve is a rectilinear valve used to control the admission of steam into and emission of exhaust from the cylinder of a steam engine. When the slide valve slides to one side, it uncovers the intake port and allows steam to fill the cylinder. This steam pushes on the piston, found inside the cylinder, and the piston in turn pushes on a rod that turns the flywheel. The flywheel turns to create motion so the steam engine can move.

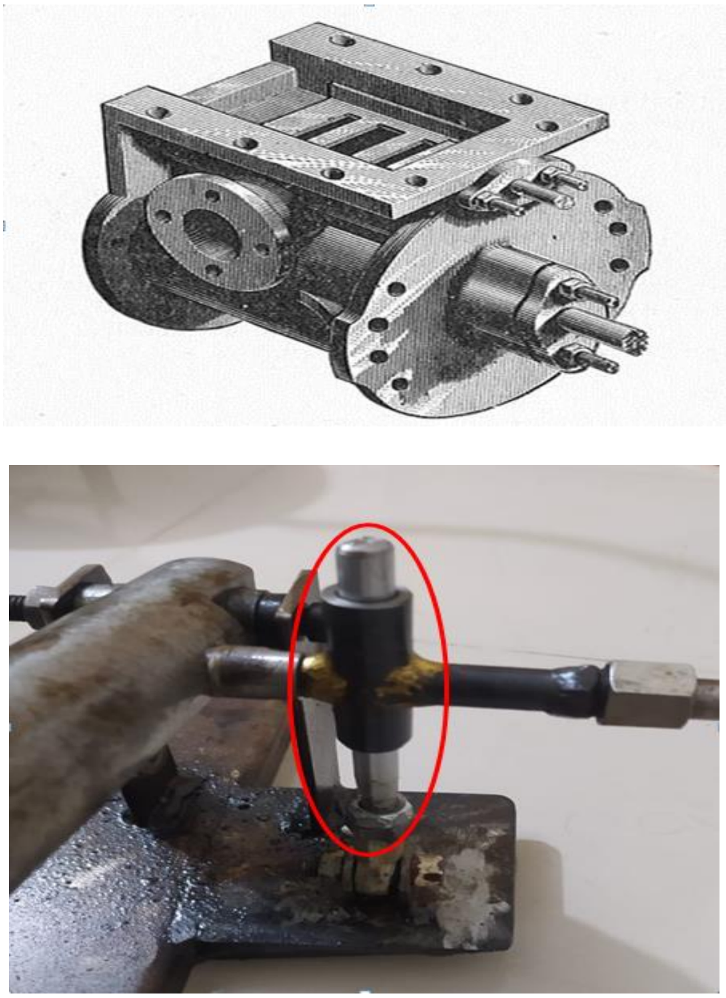


Figure3.4: Slide valve

**3.2.5 Cylinder:** A steam engine is a heat engine that performs mechanical work using steam as its working fluid. The steam engine uses the force produced by steam pressure to push a piston back and forth inside a cylinder. This pushing force can be transformed, by a connecting rod and crank, into rotational force for work. The term "steam engine" is generally applied only to reciprocating engines as just described, not to the steam turbine. Steam engines are external combustion engines,[1] where the working fluid is separated from the combustion products. The ideal thermodynamic cycle used to analyze this process is called the Ranking cycle. In general usage, the term *steam engine* can refer to either complete steam plants (including boilers etc.), such as railway steam locomotives and portable engines, or may refer to the piston or turbine machinery alone, as in the beam engine and stationary steam engine. The cylinder is the power-producing element of the steam engine powering a steam locomotive. The cylinder is made pressure-tight with end covers and a piston; a valve distributes the steam to the ends of the cylinder. Cylinders were cast in iron and later made of steel.

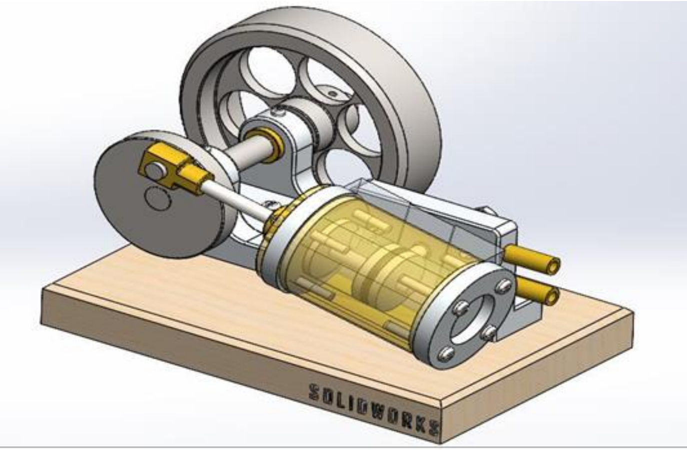



Figure3.5: Cylinder

**3.2.6 Piston:** In a reciprocating engine, the piston and cylinder type of steam engine, steam under pressure is admitted into the cylinder by a valve mechanism. As the steam expands, it pushes the piston, which is usually connected to a crank on a flywheel to produce rotary motion. Piston valves are one form of valve used to control the flow of steam within a steam engine or locomotive. They control the admission of steam into the cylinders and its subsequent exhausting, enabling a locomotive to move under its own power. The steam enters at one side of the steam cylinder through the slide valve and pushes the piston towards the opposite side. As the piston reaches the end of the stroke, the slide valve reverses the steam flow, which reverses the piston movement. A piston is a component of reciprocating engines, reciprocating pumps, gas compressors, hydraulic cylinders and pneumatic cylinders, among other similar mechanisms. It is the moving component that is contained by a cylinder and is made gas-tight by piston rings. In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and/or connecting rod. In a pump, the function is reversed and force is transferred from the crankshaft to the piston for the purpose of compressing or ejecting the fluid in the cylinder. In some engines, the piston also acts as a valve by covering and uncovering ports in the cylinder.

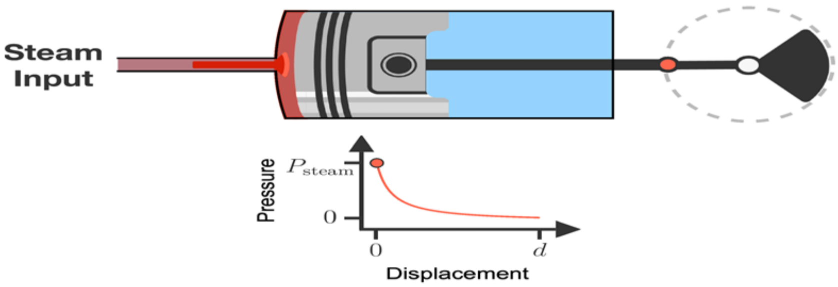



Figure 3.6: Piston

**3.2.7 Drive Wheel:** On a steam locomotive, a driving wheel is a powered wheel which is driven by the locomotive's pistons (or turbine, in the case of a steam turbine locomotive).[1] On a conventional, non-articulated locomotive, the driving wheels are all coupled together with side rods (also known as coupling rods); normally one pair is directly driven by the main rod (or connecting rod) which is connected to the end of the piston rod; power is transmitted to the others through the side rods. On diesel and electric locomotives, the driving wheels may be directly driven by the traction motors. Coupling rods are not usually used, and it is quite common for each axle to have its own motor. Jackshaft drive and coupling rods were used in the past (e.g. in the Swiss Crocodile locomotive ,but their use is now confined to shunting locomotives.

On an articulated locomotive or a duplex locomotive, driving wheels are grouped into sets which are linked together within the set.

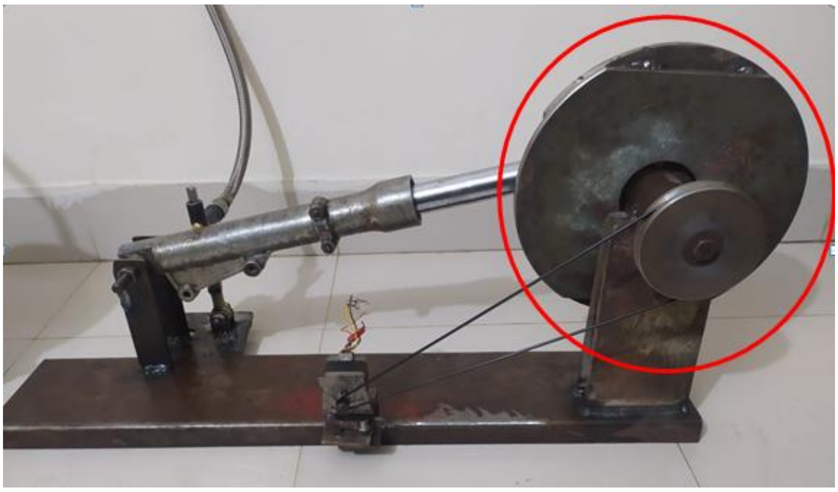
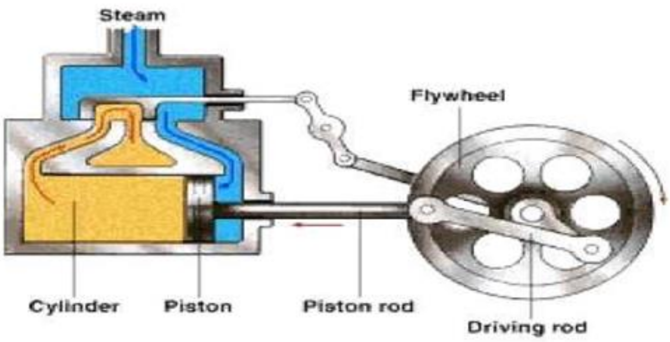


Figure3.7: Drive Wheel

**3.2.8 Inlet part:** The steam is converted to mechanical energy in the cylinders. Steam under pressure is passed through cylinder valves into a chamber and drives the piston. Boiler in the boiler, heat is added to liquid water to generate steam at a certain pressure Steam Manifold. Smaller diameter piping connects the steam header to a steam manifold. Condensate Manifold. It consists of a long trough filled with water, lying between the rails. When a steam locomotive passes over the trough, a water scoop can be lowered, and the speed of forward motion forces water into the scoop, up the scoop pipe and into the tanks or locomotive tender. Steam Manifolds are used for steam distribution in tracing applications for condensate collection. Typically used in Oil & Gas, chemical plants, petrochemical plants, textile industries, rubber plants and general industry.



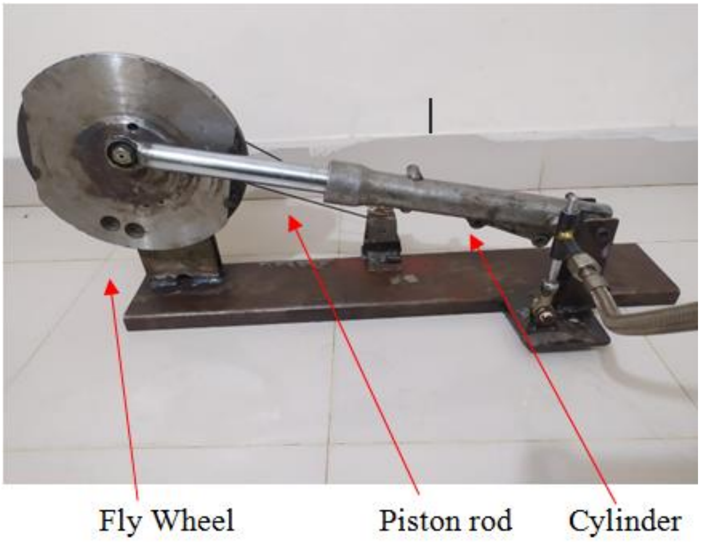




Figure3.8: Inlet part of Steam Engine

**3.2.9 Exhaust part:** The steam locomotive exhaust system consists of those parts of a steam locomotive which together discharge exhaust steam from the cylinders in order to increase the draught through the fire. It usually consists of the blast pipe, smoke box, and chimney, although later designs also include second and third stage nozzles The primacy of discovery of the effect of directing the exhaust steam up the chimney as a means of providing draft through the fire is the matter of some controversy, Ahrens (1927) devoting significant attention to this matter. The exhaust from the cylinders on the first steam locomotive – built by Richard Trevithick – was directed up the chimney, and he noted its effect on increasing the draft through the fire at the time. At Wilma, Timothy Hackworth also employed a blast pipe on his earliest locomotives, but it is not clear whether this was an independent discovery or a copy of Trevithick's design. Shortly after Hackworth, George Stephenson also employed the same method but again it is not clear whether it was an independent discovery or a copy of a design from one of the other engineers.

The locomotives at the time employed either a single flue boiler or a single return flue, with the fire grate at one end of the flue. For boilers of this design the blast of a contracted orifice blast pipe was too strong, and would lift the fire. It was not until the development of the multi-tube boiler that the centrally positioned, contracted orifice blast pipe became standard. The combination of multi-tube boiler and steam blast are often cited as the principal reasons for the high performance of Rocket of 1829 at the Rain hill Trials.

Figure3.9: Exhaust part of Steam Engine

**3.2.10 Piston Rod:** A connecting rod, also called a 'con rod', is the part of a piston engine which connects the piston to the crankshaft. Together with the crank, the connecting rod converts the reciprocating motion of the piston into the rotation of the crankshaft.[4] The connecting rod is required to transmit the compressive and tensile forces from the piston. In its most common form, in an internal combustion engine, it allows pivoting on the piston end and rotation on the shaft end. The predecessor to the connecting rod is a mechanic linkage used by water mills to convert rotating motion of the water wheel into reciprocating motion. The most common usage of connecting rods is in internal combustion engines or on steam engines.

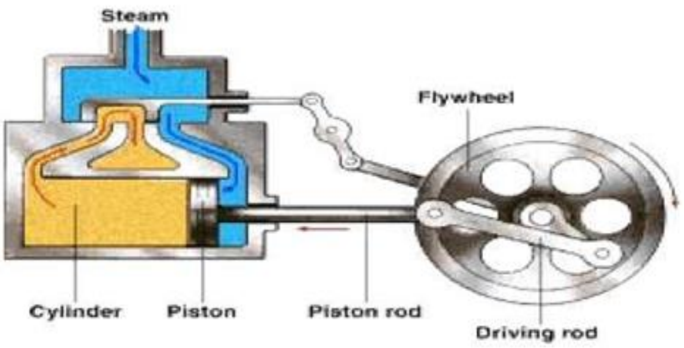



Figure3.10: Piston rod

**3.2.11 Cross head:** The crosshead of a steam engine is the sliding bearing used to support the sideways forces from the connecting rod without placing this sideways load onto the piston or piston rod seals. Trunk pistons, as used in some steam engines and most internal combustion engines, do not have a separate crosshead. A crosshead is a block or bar between the piston and the connecting rod of an engine that prevents the piston from moving from side to side and damaging the piston and cylinder. The crosshead guides the piston rod, protecting it from the sideways forces of the connecting rod. A crosshead is a mechanism used as part of the slider-crank linkages of long reciprocating engines and reciprocating compressors to eliminate sideways pressure on the piston. Also, the crosshead enables the connecting rod to freely move outside the cylinder. a heading of a subsection printed within the body of the text. Crossheading. Header, heading, head - a line of text serving to indicate what the passage below it is about; "the heading seemed to have little to do with the text.

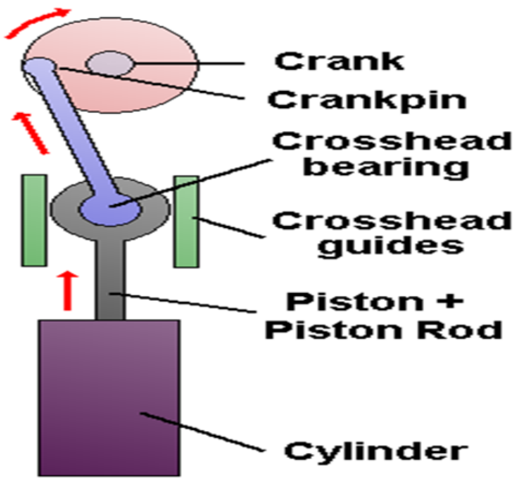



Figure3.11: Cross head

**3.2.12 Connecting rod:** In a steam locomotive, the cranks are usually mounted directly on the driving wheels. The connecting rod is used between the crank pin on the wheel and the crosshead (where it connects to the piston rod). The equivalent connecting rods on diesel locomotives are called 'side rods' or 'coupling rods'. A connecting rod, also called a 'con rod', is the part of a piston engine which connects the piston to the crankshaft. Together with the crank, the connecting rod converts the reciprocating motion of the piston into the rotation of the crankshaft.[4] The connecting rod is required to transmit the compressive and tensile forces from the piston. In its most common form, in an internal combustion engine, it allows pivoting on the piston end and rotation on the shaft end. The predecessor to the connecting rod is a mechanic linkage used by water mills to convert rotating motion of the water wheel into reciprocating motion.[5] The most common usage of connecting rods is in internal combustion engines or on steam engines. The predecessor to the connecting rod is the mechanical linkage used by Roman-era watermills. The earliest known example of this linkage has been found at the late 3rd century Hierapolis sawmill in Roman Asia (modern Turkey) and the 6th century saw mills at Ephesus in Asia Minor (modern Turkey) and at Grease in Roman Syria. The crank and connecting rod mechanism of these machines converted the rotary motion of the waterwheel into the linear movement of the saw blades.

An early documentation of the design occurred sometime between 1174 and 1206 AD in the Artois State (modern Turkey), when inventor Al-Jazari described a machine which incorporated the connecting rod with a crankshaft to pump water as part of a water-raising machine,[7][8] though the device was more complex than typical crank and connecting rod designs.[9]: 170 There is also documentation of cranks with connecting rods in the sketch books of Tuscola from Renaissance Italy and 15th century painter Pirandello.

Figure3.12: Connecting rod

A crankshaft is a mechanical component used by in a piston engine to convert the reciprocating motion into rotational motion. The crankshaft is a rotating shaft containing one or more crankpins,[1] that are driven by the pistons via the connecting rods. The crankpins are also called rod bearing journals, and they rotate within the "big end" of the connecting rods. Most modern crankshafts are located in the engine block. They are made from steel or cast iron, using either a forging, casting or machining process. The crankshaft located within the engine block, held in place via main bearings which allow the crankshaft to rotate within the block.[3] The up-down motion of each piston is transferred to the crankshaft via connecting rods.[4] A flywheel is often attached to one end of the crankshaft, in order to smoothen the power delivery and reduce vibration.

A crankshaft is subjected to enormous stresses, in some cases more than 8.6 tonnes (19,000 pounds) per cylinder. Crankshafts for single-cylinder engines are usually a simpler design than for engines with multiple cylinders.

Figure3.13: Crankshaft

**3.2.13 Eccentric rod:** In mechanical engineering, an eccentric is a circular disk (eccentric sheave) solidly fixed to a rotating axle with its center offset from that of the axle (hence the word "eccentric", out of the center). It is used most often in steam engines, and used to convert rotary motion into linear reciprocating motion to drive a sliding valve or pump ram. To do so, an eccentric usually has a groove at its circumference closely fitted a circular collar (*eccentric strap*). An attached *eccentric rod* is suspended in such a way that its other end can impart the required reciprocating motion. A return crank fulfills the same function except that it can only work at the end of an axle or on the outside of a wheel whereas an eccentric can also be fitted to the body of the axle between the wheels. Unlike a cam, which also converts rotary into linear motion at almost any rate of acceleration and deceleration, an eccentric or return crank can only impart an approximation of simple harmonic motion. The term is also used to refer to the device often used on tandem bicycles with timing chains, single-speed bicycles with a rear disc brake or an internal-geared hub, or any bicycle with vertical dropouts and no derailleur, to allow slight repositioning, fore and aft, of a bottom bracket to properly tension the chain. They may be held in place by a built-in wedge, set screws threaded into the bottom bracket shell, or pinch bolts that tighten a split bottom bracket shell. As a standard sized bottom bracket threads into the eccentric, an oversized bottom bracket shell is required to accommodate the eccentric.

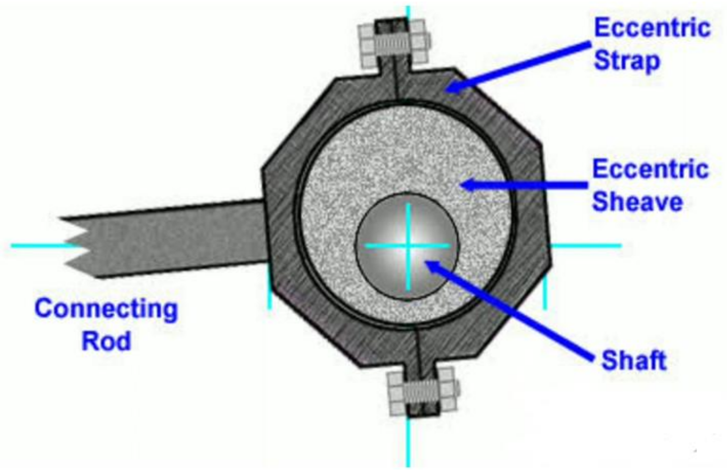



Figure1.14: Eccentric

**3.2.14 Flywheel of Steam Engine:** A flywheel is a mechanical device which uses the conservation of angular momentum to store rotational energy; a form of kinetic energy proportional to the product of its moment of inertia and the square of its rotational speed. In particular, assuming the flywheel's moment of inertia is constant (i.e., a flywheel with fixed mass and second moment of area revolving about some fixed axis) then the stored (rotational) energy is directly associated with the square of its rotational speed. Since a flywheel serves to store mechanical energy for later use, it is natural to consider it as a kinetic energy analogue of an electrical inductor. Once suitably abstracted, this shared principle of energy storage is described in the generalized concept of an accumulator. As with other types of accumulators, a flywheel inherently smooth sufficiently small deviations in the power output of a system, thereby effectively playing the role of a low-pass filter with respect to the mechanical velocity (angular, or otherwise) of the system. More precisely, a flywheel's stored energy will donate a surge in power output upon a drop in power input and will conversely absorb any excess power input (system-generated power) in the form of rotational energy. Common uses of a flywheel include smoothing a power output in reciprocating engines, energy storage, delivering energy at higher rates than the source, controlling the orientation of a mechanical system using gyroscope and reaction wheel, etc. Flywheels are typically made of steel and rotate on conventional bearings; these are generally limited to a maximum revolution rate of a few thousand RPM.[1] High energy density flywheels can be made of carbon fiber composites and employ magnetic bearings, enabling them to revolve at speeds up to 60,000 RPM (1 kHz). Flywheels are often used to provide continuous power output in systems where the energy source is not continuous. For example, a flywheel is used to smooth the fast angular velocity fluctuations of the crankshaft in a reciprocating engine. In this case, crankshaft flywheel stores energy when torque is exerted on it by a firing piston and then returns that energy to the piston to compress a fresh charge of air and fuel. Another example is the friction motor which powers devices such as toy cars. In unstressed and inexpensive cases, to save on cost, the bulk of the mass of the flywheel is toward the rim of the wheel. Pushing the mass away from the axis of rotation heightens rotational inertia for a given total mass. A flywheel may also be used to supply intermittent pulses of energy at power levels that exceed the abilities of its energy source. This is achieved by accumulating energy in the flywheel over a period of time, at a rate that is compatible with the energy source, and then releasing energy at a much higher rate over a relatively short time when it is needed. For example, flywheels are used in power hammers and riveting machines. Flywheels can be used to control direction and oppose unwanted motions. Flywheels in this context have a wide range of applications: gyroscopes for instrumentation, ship stability, satellite stabilization (reaction wheel), keeping a toy spin spinning (friction motor), stabilizing magnetically-levitated objects (Spin-stabilized magnetic levitation). Flywheels may also be used as an electric compensator, like a synchronous compensator, that can either produce or sink reactive power but would not affect the real power. The purposes for that application are to improve the power factor of the system or adjust the grid voltage. Typically, the flywheels used in this field are similar in structure and installation as the synchronous motor (but it is called synchronous compensator or synchronous condenser in this context). There are also some other kinds of compensator using flywheels, like the single-phase induction machine. But the basic ideas here are the same, the flywheels are controlled to spin exactly at the frequency which you want to compensate. For a synchronous compensator, you also need to keep the voltage of rotor and stator in phase, which is the same as keeping the magnetic field of rotor and the total magnetic field in phase (in the rotating frame reference).

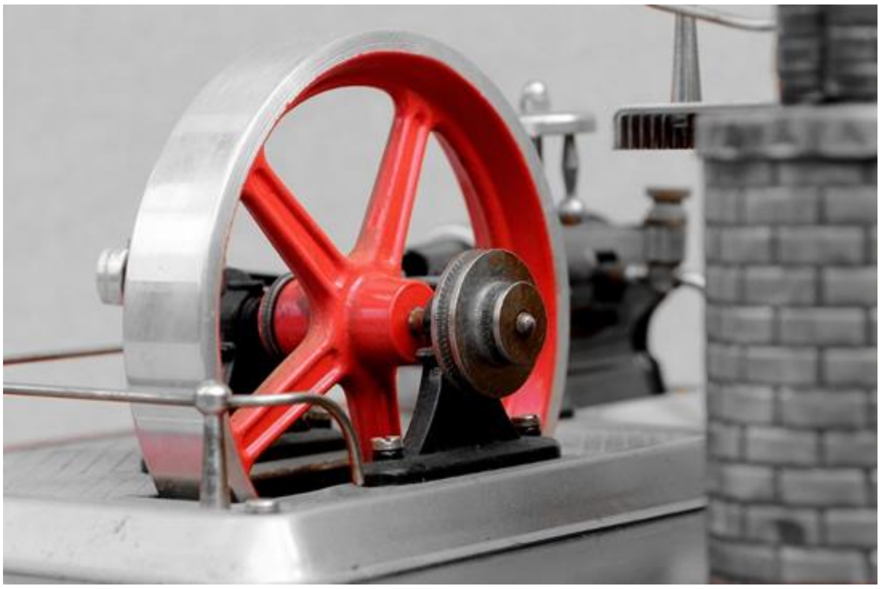


Figure3.15: Flywheel

**3.2.15 Governor:** A governor is a specific type of governor with a feedback system that controls the speed of an engine by regulating the flow of fuel or working fluid, so as to maintain a near-constant speed. It uses the principle of proportional control.

Centrifugal governors, also known as "centrifugal regulators" and "fly-ball governors", were invented by Christian Huygens and used to regulate the distance and pressure between millstones in windmills in the 17th century.[1][2] In 1788, James Watt adapted one to control his steam engine where it regulates the admission of steam into the cylinder(s),[3] a development that proved so important he is sometimes called the inventor. Centrifugal governors' widest use was on steam engines during the Steam Age in the 19th century. They are also found on stationary internal combustion engines and variously fueled turbines, and in some modern striking clocks.

A simple governor does not maintain an exact speed but a speed range, since under increasing load the governor opens the throttle as the speed (RPM) decreases. The devices shown are on steam engines. Power is supplied to the governor from the engine's output shaft by a belt or chain connected to the lower belt wheel. The governor is connected to a throttle valve that regulates the flow of working fluid (steam) supplying the prime mover. As the speed of the prime mover increases, the central spindle of the governor rotates at a faster rate, and the kinetic energy of the balls increases. This allows the two masses on lever arms to move outwards and upwards against gravity. If the motion goes far enough, this motion causes the lever arms to pull down on a thrust bearing, which moves a beam linkage, which reduces the aperture of a throttle valve. The rate of working-fluid entering the cylinder is thus reduced and the speed of the prime mover is controlled, preventing over-speeding.

Mechanical stops may be used to limit the range of throttle motion, as seen near the masses in the image at right.

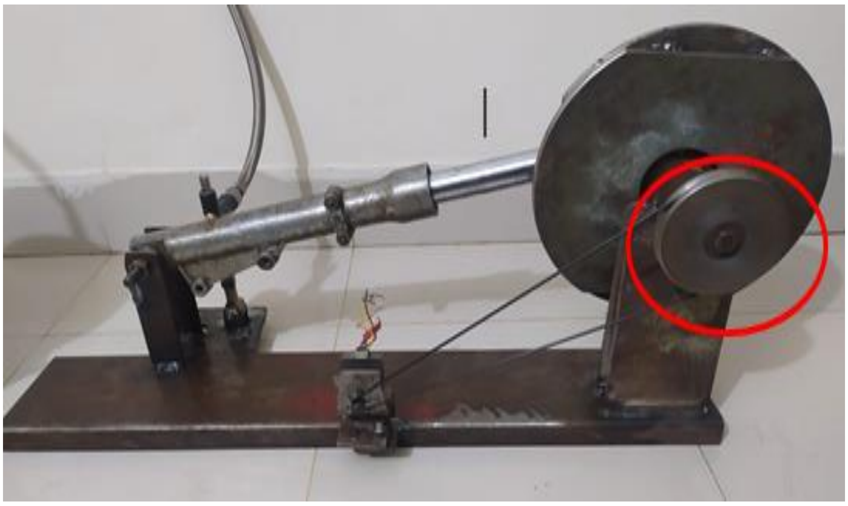


Figure3.16: Governor

Electricity forecasting is a very important tool in the energy industry. Electricity demand forecasting is an essential part of the electricity industry. It is widely used for planning towards building new power generating plants, energy resources demand planning, expansion of electricity supply network, policy making, electricity market analysis and many more reasons. Electricity demand forecasting provides enough data to make calculated and informed decision. Over the years, several methods have been developed to carry out electricity demand forecast. Each method has its advantages and disadvantages depending on the available data and the peculiarity of the country where the data is acquired. Nigeria has had deficit in the electricity industry due to improper planning for electricity supply. We are reviewing the different techniques which have been proposed for the purpose of electricity demand forecasting by various researchers and their different advantages depending on which one is applicable to a given situation. Techniques that are adaptive and accurate like artificial neural network are beneficial for forecasting in a situation where there is indirect relationship between the dataset. Making use of forecasting techniques will provide enough information for making informed decision that will help Nigeria meet the its growing electricity need and also manage its internal energy consumption efficiently in a ley man definition, energy is the capacity to do work. Energy exists in many forms for example heat, light, chemical, rotary, electrical or mechanical energy. Although energy is used by man to do work, not all energy can be directly harnessed. They have to be converted from one form to the other to be able to meet the needs which they are required to meet. Modern civilization with all its technological advancements was achieved only because man mastered the art of converting energy from one form to the other for his use. In our solar system, the sun is the only star. It is surrounded by planets and radiates solar energy which is transferred to earth through space. The energy from the sun supports life on earth. This energy is absorbed by plants and animals enabling them to survive. Solar energy from the sun is used to convert water and carbon dioxide into oxygen and carbohydrates in a process known as oxygenic photosynthesis. This is a natural process which converts solar energy directly into chemical energy. In the same way, the human body is designed to extract energy when food is consumed in a process called metabolism. With this energy, the body functions to produce heat and feed the muscles with the fuel to do work. Energy is a primary ingredient of life which is an important part of the world. Work can be defined as energy transfer which occurs when an object is moved over a distance by an external force. Man, initially relied on their physical strength to do work at the very early civilizations using crude tools to assist in hunting and gathering. In the Paleolithic period, hunting and gathering, fishing and chasing game all around the world as a means of survival. This survival method using crude stone tools required lots of energy. The discovery of fire was a milestone in the history of mankind and there are evidence that shows that the earliest control of fire by homo sapient man was done about 1.7 to 2 million years ago[2]. At this time fire was used mostly for heating during the winter, cooking and protection from wild animals. Gradually man evolved, learning to properly harness the heat energy to producing more useful work. The industrial revolution was a major turning point in human history. The industrial revolution describes the period whereby humanity had a speedy technological transformation and within this period the internal combustion engine was discovered. The invention of the internal combustion engine was a tipping point in the industrial revolution. Internal combustion engines were more efficient than the steam engines which brought about the industrial revolution. They had lesser weight and packed more power. This meant more powerful and efficient machines for textile and agricultural industries as well as for transportation and other uses. Nuclear energy was discovered towards the end of the industrial revolution. Nuclear energy which was initially being researched to be used a weapon was discovered to produce enough heat energy capable of being used in steam turbines for generating electricity. Electricity is an important need today. It is used for residential, transportation, industrial, military and many other applications. Useful electricity is not found naturally in nature hence it is called a secondary energy This is because it is derived from the conversion of primary energy source e.g. fossil fuel, wind energy, solar energy etc. The importance of electricity in the modern era cannot be over emphasized. It is so important that a lack of electricity will be a disaster. Electricity was largely produced by combusting fossil fuel in energy conversion machines. The combustion of fuel in the energy conversion machines produced rotary motion used in rotating big generators. Some renewable energy resources are used for generating electricity but it makes up a small percentage when compared to fossil fuel. Fossil fuel dependent energy conversion technologies like gas turbines, steam turbines, and reciprocating internal combustion engines had the advantage of being cheaper in terms of compared to renewable conversion technologies. Fossil fuel is abundantly found in nature and over the years, the technologies for mining have improved greatly thereby driving the cost down. Until the invention of nuclear energy which produced a cleaner type of electricity, fossil fuel was the most preferred source for the generation of electricity. However, everything that has an advantage also has a disadvantage. Nuclear energy produces nuclear waste after it is used to generate electricity. Management of nuclear waste is a major issue because of the long half-life of the spent nuclear fuel. This means that the spent fuel must be properly stored and disposed in a safe way in other not to pose harm to humans Till date, the disposal of nuclear waste poses big problem. This disadvantage greatly affected the adoption of nuclear power as the main source of electrical energy worldwide. In recent times, there has been so much concern on global warming and sustainability. Global warming is largely due to emission of green-house gases (GHG). Green-house gases like carbon dioxide which is a combustion product when fossil fuel is combusted is very harmful to nature due to their harmful effect on the atmosphere. The usage of fossil fuel degrades the environment over time. A sustainable energy resource is a resource that readily and sustainably available at a cost which is reasonable and can be utilized for all energy applications without causing any negative impact to the society [4]. Researching into renewable energy resources and technologies is a very important component of sustainable development. This is because they have less environmental impact compared to other energy resources, they cannot be depleted and they favor a more decentralized power system. This would mean gradual transition from fossil fuel dependence to renewable energy sources and greener alternatives for electricity generation in the future. Natural gas is favored as a transition energy resource because it has very low emission when compared with other non-renewable sources. However, just like all other non-renewable sources, it is limited in nature. As with all commodities which are core to the human society, electricity is greatly affected by economic forces like demand and supply. Some of the main challenges with transformation of energy from fossil to renewable energy resources are energy storage cost of the system, lifetime of the system and grid reliability. Apart from the technical performance of a renewable energy technology, the commercial feasibility is also very important. The cost of deploying a renewable energy technology is very important to the investor because the technology must show that it is viable and can compete with the cost of investing in other energy conversion technologies. The cost of transitioning to more green electricity generating technologies is high. These factors and many more affect what shapes the future of electricity generation. With growing population and advancement in technology which require more energy, there is even more economic strain on electricity as a commodity. One property of electricity which makes it a unique commodity is that it is consumed as it is produced. There are few technologies currently available to store electricity but they are still a long short away from meeting electricity demand for huge demand and a long time. Electricity demand must always match the supply. There is a need to properly plan and manage the generation of electrical energy. The costs associated with expanding power generation, increasing electricity demand due to increasing population growth, increasing energy needs due to technological advances, ensuring smooth transitioning to renewable energy technologies for electricity generation means that electricity generation must be carefully planned in order to meet both present and future demands. Every country differs in its electricity demand due to several factors like population, technological advancement, political environment etc. These factors must be considered by the governments in order to plan towards present and future energy needs of their country. Governments need to plan ahead to be able to properly utilize limited resources and also meet the energy needs of their people. Forecasting of energy demand is one-way governments of various countries ensure they provide for their energy needs. Electricity demand helps the government plan for future electricity demand growth, energy resources utilization, electricity generation expansion. Forecasting plays a very important role in allocation of electricity, planning for future power generation facilities with a proper demand forecast, the government can as well use the information to plan towards transitioning to renewable energy resources.

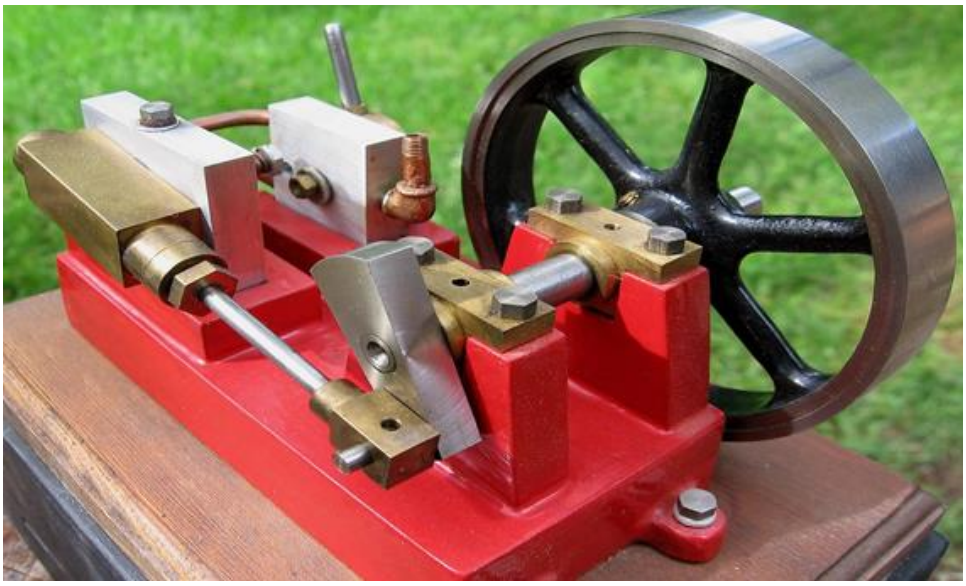


Figure3.17: Governor

Without proper forecasting, electricity demand will never be able to match with the supply. Forecasting is a technique that makes use of historical data to project future estimates that are predictive of a future trend. It is a very important tool for planning. Electricity is an important commodity in the world today. It is important for the development of nations. Basically, all spheres of a society require electricity in order to function optimally. The importance of electricity makes it a resource which should not be played with. Careful planning is required to be able to provide for the growing demand of electricity. Forecasting is the right tool used for this. By making use of historical electricity demand, the future demand is estimated in a trend. The result of the forecast is used to plan for new power stations which will argument the demand for electricity in the future. Electrical forecasting is important because it helps a nation plan for generation; plan for its transmission expansion and also for financial planning. Further to all of this, electricity forecasting helps with planning for the spinning reserve required for the future demand, also the fuel required for the future electrical demand and other aspect of planning which will ensure an efficient delivery of electricity This article will help to give an insight on how to forecast electricity demand. Lots of work has been done over the years on electricity demand forecasting. Researchers have presented different ways to carry out electricity demand forecasting. Conventional methods have been used over the years and newer methods have been proposed along with hybrid methods which were developed to improve the accuracy of forecasting. Some work has been carried out to compare all these techniques developed with each other to ascertain the most accurate among them. This work will help give a good understanding of the works that have been done in the field of electricity demand forecasting and serve as a guide to select the appropriate technique in different situations.

## Chapter 4

# Operational Outcome

### 4.1 Working Procedure:

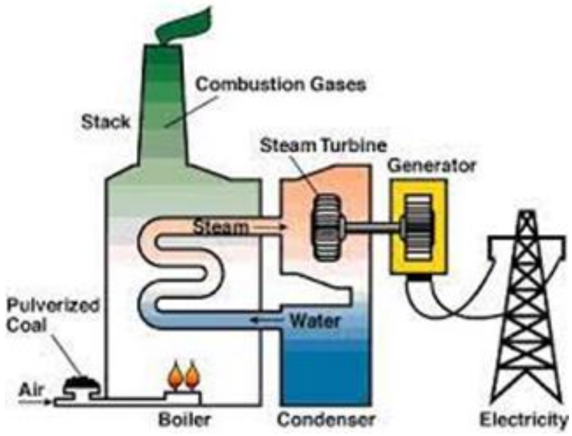



Figure 4.1: A steam electric power plant powered by a boiler

Making electricity from steam is generally a three-step process, where water is converted to high pressure steam, then the high-pressure steam is converted to mechanical rotation of a turbine shaft, and the rotating turbine shaft then drives an electric generator. Step 1: Water to Steam In steam electric power plants, water is usually converted to high pressure steam using one of the following options: - A boiler, which creates heat energy by burning fuels such as coal, oil, natural gas, wood or municipal waste as shown in Figure 6.1.3 - Geothermal energy, which is the heat energy in the ground near the Earth’s core, as shown in Figure 6.2. Geothermal energy exploration involves finding blocks of underground radioactive ‘hot rocks’ which contain fractures through which water can pass. The proposition is that these support electricity generation by water being injected, circulated through the fractures, and then returned to surface as steam. South Australia has been described as ‘Australia's hot rock haven’. According to an estimate by the Centre for International Economics, Australia has enough geothermal energy to contribute electricity for 450 years. 4 A geothermal power plant is already generating 80 kW of electricity at Burnsville, in southwest Queensland. 5 - Atomic fission, which creates heat energy by splitting large atoms in to

**4.2 Fundamentals:**

The pressure of a gas in an enclosure varies with temperature (if the volume remains the same)

- Pressure *temperature the heat energy is absorbed by the gas particles, which then become More active and thus have more frequent and forceful collisions with each other and the enclosure's walls. These collisions cause pressure.

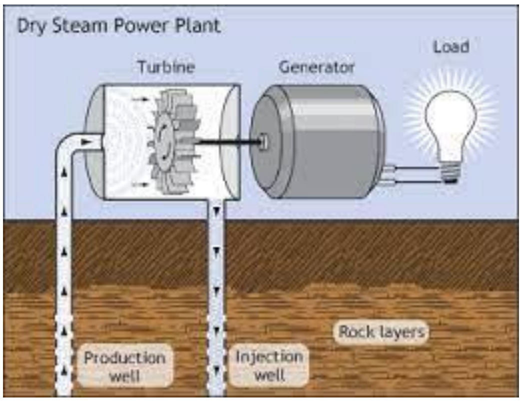



Figure 4.2: A steam electric power plant powered by geothermal energy

Convert High Pressure Steam to Mechanical Rotation Steam Turbines convert high pressure steam to mechanical rotation. Their power output can range from 0.5 megawatts to over 1300 megawatts.11 Steam turbines convert 10-40 percent of the combined input pressure potential energy and linear kinetic energy of steam to output rotational kinetic energy of the turbine shaft12 - High-pressure steam (high pressure potential energy) and with some velocity (linear kinetic energy) enters the turbine and is sucked through sets of different turbine blades, exiting at atmospheric pressure in the following process:- The steam first encounters a set of stationary blades, which are also converging nozzles, that guide the steam towards the next set of blades. The steam then encounters a set of moving blades, called rotor blades, which are connected to the turbine shaft such that when the rotor blades move, the turbine shaft rotates (rotational kinetic energy). - Each pair of nozzles and rotor blades is called a stage. Some turbines use multiple stages in succession to convert as much steam energy into shaft energy as is economical. The energy conversion as the steam flows through the blades depends on whether the turbine is an impulse turbine or a reaction turbine. The difference between these two types of turbines lies in their blade configurations. Each blade configuration uses a different type of primary force (impulse or reaction) to move the rotor blades, but also uses the other type of force (reaction or impulse) secondarily. The two can also be combined into an impulse-reaction configuration, relying heavily on both impulse and reaction

Table I: Symbol Nomenclature for Equation

| Symbol | Quantity | Unit |
|---|---|---|
| I | Electrical current generated in wire Ampere | (A) |
| F | Force acting on current-carrying wire Newton | (N) |
| B | Magnetic field strength acting on wire Tesla | (T) |
| I | Length of wire meters | (m) |
| θ | Angle between the force and magnetic field strength | Degree (o) |

Almost all coal, nuclear, geothermal, solar thermal electric power plants, waste incineration plants as well as many natural gas power plants are steam-electric. Natural gas is frequently combusted in gas turbines as well as boilers. The waste heat from a gas turbine can be used to raise steam, in a combined cycle plant that improves overall efficiency.

Worldwide, most electric power is produced by steam-electric power plants.[1] The only widely used alternatives are photo voltaic, direct mechanical power conversion as found in hydroelectric and wind turbine power as well as some more exotic applications like tidal power or wave power and finally some forms of geothermal power plants.[2] Niche applications for methods like beta voltaic or chemical power conversion (including electrochemistry) are only of relevance in batteries and atomic batteries. Fuel cells are a proposed alternative for a future hydrogen economy.

Table II: future hydrogen economy

| **Symbol** | **Quantity** | **Unit** |
|---|---|---|
| V | Voltage generated across load | Volts (V) |
| I | Electrical current generated in wire | Ampere (A) |
| Z | Electrical impedance of load | Ohm (Ω) |

## 4.3 Efficiency:

The efficiency of a conventional steam-electric power plant, defined as energy produced by the plant divided by the heating value of the fuel consumed by it, is typically 33 to 48%, limited as all heat engines are by the laws of thermodynamics (See: Carnot cycle). The rest of the energy must leave the plant in the form of heat. This waste heat can be removed by cooling water or in cooling towers. Cogeneration uses the waste heat for district heating. An important class of steam power plants is associated with desalination facilities, which are typically found in desert countries with large supplies of natural gas. In these plants freshwater and electricity are equally important products.

Since the efficiency of the plant is fundamentally limited by the ratio of the absolute temperatures of the steam at turbine input and output, efficiency improvements require use of higher temperature, and therefore higher pressure, steam. Historically, other working fluids such as mercury have been experimentally used in a mercury vapor turbine power plant, since these can attain higher temperatures than water at lower working pressures. However, poor heat transfer properties and the obvious hazard of toxicity have ruled out mercury as a working fluid.

Another option is using a supercritical fluid as a working fluid. Supercritical fluids behave similar to gases in some respects and similar to liquids in others. Supercritical water or supercritical carbon dioxide can be heated to much higher temperatures than are achieved in conventional steam cycles thus allowing for higher thermal efficiency. However, these substances need to be kept at high pressures (above the critical pressure) to maintain super criticality and there are issues with corrosion.

**Chapter – 5**

# ELECTRICITY DEMAND FORECASTING

## 5.1 Electricity Demand

Electricity demand forecast can be categorized into different groups. These are groups are based on the duration of the forecast which is conducted. The duration of the forecast is called forecast ranges. An accurate forecast is necessary for planning of electric power systems. This helps to plan for maintenance, scheduling, expansion and many other reasons. The purpose of the forecast determines the range the forecast will be done. Several factors affect electricity demand in different

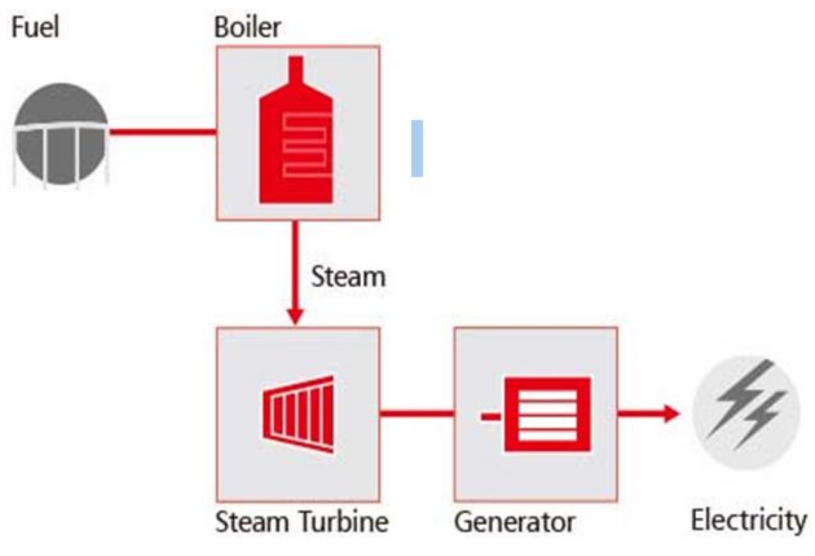



Figure 5.1: Electricity Demand

regions. Also, the duration of the forecast determines the influence certain factors have on the dependent variable ‘electricity demand’ which in turn affects the electricity forecast. Factors like weather, demographic variables, socio-economic factors, relative humidity, population, gross domestic product etc. They are carefully selected depending on the range and type of the forecast. Electricity Demand Forecasting Ranges: There are different forecasting ranges which are short term, medium term and long-term Short-Term Forecasting: The range of the forecast is dependent on the period of study. Short term electricity forecasting is usually referred to as hourly load forecast. It helps with day-to-day operation of utilities, electricity generation nomination, planned maintenance etc. This type of electricity demand forecast would consider factors that affect daily generation of electricity from previous data. Examples of such factors are weather, humidity, ambient temperature, human activities etc. Medium Term Forecasting: Medium term forecasting is in the range of weeks to a few years. This forecasting is necessary in planning fuel consumption scheduling, unit maintenance and other economic decisions. Forecasting electricity for medium term will consider factors that can affect medium term electricity generation; factors like weather, ambient temperature, season etc. This type of forecasting will help with maintenance planning in power generating stations, planning of fuel supply, expansion of generating plants, etc. Long Term Forecasting: Long term forecasting is known as the annual peak load and annual energy forecast. It is usually forecasted for a range of 5 to 25years. This type of forecast considers factors that affect long term electricity demand. Examples of some of these factors are GDP, seasons, population etc. Long term electricity forecast helps with planning towards the expansion of power generation plants, grid expansion, and energy resources usage and demand and policy creation. Classification of Forecasting Techniques: The use of forecasting techniques for electricity demand forecasting has been in use for a long time. Over the years different techniques have been developed for electricity demand forecasting and there are still new techniques being developed till date. Some of these techniques have been used for ages while some are more recent. According to Singh et al forecasting is classified into 3 types namely;

- Traditional forecasting techniques,
- Modified forecasting techniques
- Soft computing techniques.

Each of the three forecasting techniques is discussed in turn. Traditional Forecasting Techniques: Traditional forecasting techniques have been used for years to carry out energy forecast. Regression is a statistical technique which is used to establish the relationship between two variables. Once the relationship is established, it can be forecasted using the relationship already defined. Different types of regression techniques have been developed over the year. Examples of some data driven techniques used for forecasting are multivariate adaptive regression spline (MARS), support vector regression (SVR), autoregressive integrated moving average (ARIMA), exponential smoothening (ES), kernel regression (also known as Nadaraya-Watson Estimator). Tradition forecasting techniques are methods used in forecasting using mathematical regression. Traditional forecasting techniques include regression, multiple regression, exponential smoothing and iterative reweighted least-squares technique. These methods are known as the traditional forecasting method because they are mathematical methods used in the early days to forecast. Regression technique is a very common forecasting technique.

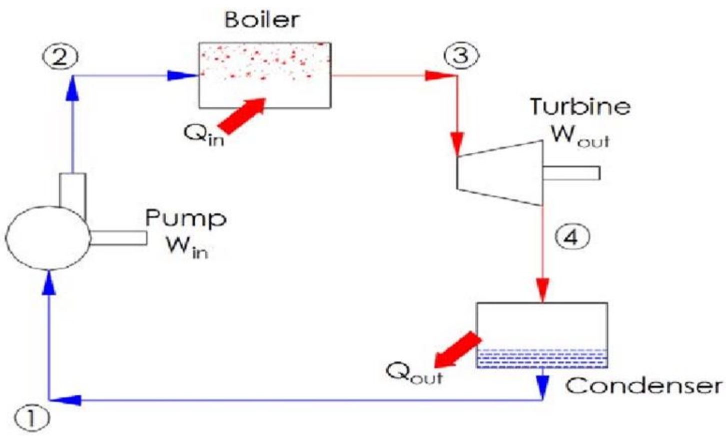



Figure 5.2: Traditional forecasting techniques

It can be employed in different fields of study. In the case of electricity demand forecasting, it is used to model the relationship between load demand factors like weather condition. The method uses previous historical data to predict future by modeling the pattern and finding the relationship between the factors that affect the parameter. Regression technique is used when the factors considered are few. Linear regression is technique used to find the relationship between different variables. The relationship found between two variables tested is called the simple linear regression while if it is found between more than two variables, it is called multi variable linear regression. Once the relationship is established between the variables, it can easily be projected to produce the forecast for that variable given the factors remain constant. Reddy et al carried out a study to forecast the short term load demand for Rajiv Gandhi University of Knowledge Technologies-AP (RGUKT R. K) valley substation. Data was collected 30minutes every day for a month. The only known data was the load data collected and a linear regression technique was applied to forecast the load. To confirm the accuracy of the results, the performance was checked with least square error (LSE) method and mean squared error (MSE). The results obtained gave an LSE error of 132.4821 and an MSE error of 6.0219. Also root mean square error (RMSE) technique and mean absolute percentage error (MAPE) gave an error resulting in 2.453 and 0.029 respectively. Ade-iceman et al [10] explored the use of regression analysis to forecast the yearly consumption of electricity in O gun state. Data was collected between 2016 and 2017 for the purpose of this research. The independent variable used was population and this data was also collected for the year in view. A Malthusian population growth equation was used to model the population growth for the work. The forecast range was for 10 years (2019-2028). The result obtained showed a linear increase between the variables, 3.5% increase was recorded over the range of forecast (10years). The forecasted value for the energy consumed in O gun state at the end of the forecast period stood at 1,365,024MWh which is a 53% increase from the start of the forecast. The error derived for energy demand forecast stood at 5.98%. Multiple regressions are used when the factors affecting main parameter being forecasted are many.

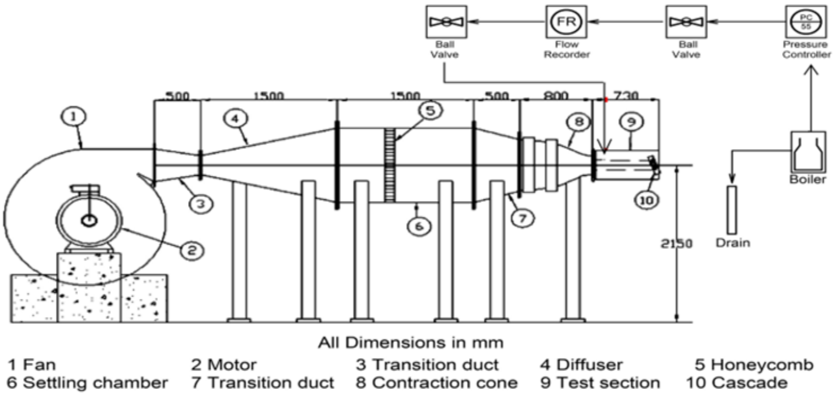



Figure 5.3: Modified forecasting techniques

The factors include weather, GDP, price of electricity and economic growth. Multiple regression uses the least square estimation. The least square method is a mathematical method which is used to determine the line of best fit in a data set thereby providing visually the relationship between data-points. This method is used to predict the way dependent variables behave and provides the rationale for the placement of the best fit lines among data-points. Overran and King carried out a study to investigate short term demand forecast for South Sulawesi Island in Indonesia. They applied the multiple linear regression method. Data was acquired during the rainy season and the dry season for the purpose of this study. The result obtained during the study contained several components of error. Modeling error introduced during regression, error caused by system disturbances and error of temperature forecast. The model was observed to be very sensitive to temperature change whereby a small change in temperature caused a significant change in load prediction. The results obtained from the mean average percentage error were 3.52% for dry season and 4.34% for the rainy season. Vasquez et al worked on the forecasting the energy consumption of Puerto prices, a distribution system for the year 2019-2028 using multi linear regression. The variables for this study were peak demand and number of customers. Load demand data was collected from the utility for a period of 10 years between 2014 – 2018.The results of the energy forecast in 2028 were projected at 566,078,019.1kWh. The regression results had an error performance of 0.995 and 0.991 with the mean average percentage error of 0.74% showing that the model developed is a good fit for the data set. Sara vanan et al [13] studied the electricity demand forecast for India using regression analysis using artificial neural network and regression analysis with principal components. The forecast was done for a period of 19 years starting from 2012 to 2030. The input variables selected were amount of CO2emission, population, per capita

GDP, per capita gross national income, gross domestic savings, consumer price index, whole sale price index, imports, exports, per capita power consumption. The technique used combines statistical and artificial technique. Root means square error (RMSE), mean absolute percentage error (MAPE) and mean bias error (MBE) were used to measure the accuracy of the results obtained from the forecast. The result obtained from the forecast showed that the artificial neural network with principal components (PC-ANN) had the most accurate forecast. MAPE for the PC-ANN resulted in 0.430% compared to 0.597% for Principal component regression (PCR) and 0.969% for regression analysis. The use of ANN gave more precise results compared to multi linear regression and PCR. The research concluded that PC-ANN approach was a suitable and accurate method for forecasting. A time series data is a sequence of data collected in the order of time. It typically consists of data points measurements collected from the same source at an interval which is used to track changes of the particular data point over time. This data point can be analyzed using

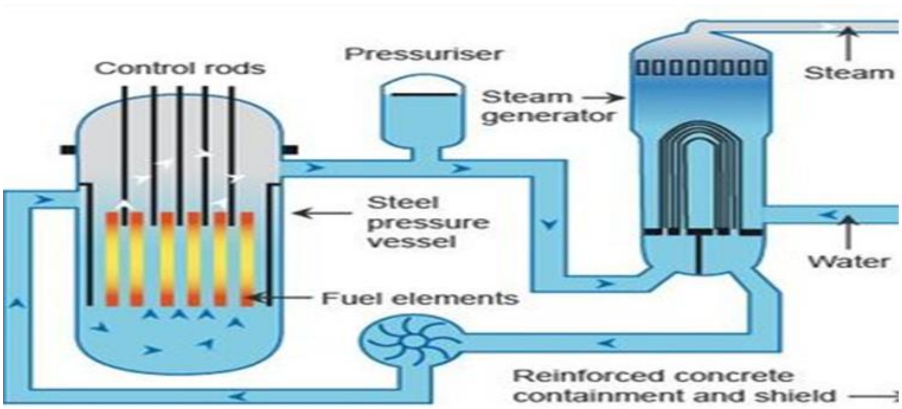



Figure 5.4: Soft computing techniques**.**

Regression methods to find a pattern or relationship with other variables. Exponential smoothing is a method whereby dependent data is modeled based on previous data and then the model is used to predict the future. Exponential Smoothing is used for smoothing time series data using the exponential window function. This is done by using an exponential smoothing calculation which is called a smoothing factor. In this method exponentially decreasing weights are applied over time. It can be easily applied for determining forecast using previous assumptions. Exponential smoothing is a time series methods and it arises from monitoring industrial processes or tracking data. the data points taken over time in a time series method over time have an internal structure such as autocorrelation trend or seasonal variation. Exponential smoothing is based on times series and it takes into consideration the history of consumption so as to find a pattern in the past that is similar to present curves. This technique applies exponentially decreasing weights from recent observations to older observations. This will generate smoothed values which will be used to obtain the estimates. There are different exponential smoothing types which are the first order, second order, higher order exponential smoothing and the holts-winters mechanism Bandit et al carried out a study on a fittings manufacturer in Cluj-Napoca. The aim of the study was to carry out day a head load forecast using the Holt-Winters method. The data was collected for about 4 months and then the forecast was done for a week. They argued that if the time series is stationary and the trend is similar to the past with little variance in time then exponential smoothing can be used instead of other more sophisticated methods that could easily introduce errors. The study modeled the load forecast of an industrial costumer who has a pretty fixed operation cycle therefore the load consumption is repeated and almost similar with historical data. The result was tested for accuracy using MSE and MAPE technique and it showed the MSE had better values within the acceptable limit but the MAPE had values which were too large or outside the acceptable range. From the result of the MAPE, the forecast carried out was not accurate enough to be depended on for a forecast. Contreras-Salinas and Rodriguez applied the Holt's method to forecast electricity demand in Colombia. Other parameters were also factored in in calculating the forecast. These are energy consumption, per capita GDP, purchasing power parity which they considered directly affects the behavior of the energy demand. Data was collected from the national interconnected system (SIN) and World bank to carry out the study for a period of 10 years spanning 2007 - 2017. Using the Holt's method, a forecast for a period of 2018, 2019 and 2020 was done. The results obtained showed an increase in energy consumption grew slightly from 66,231GWk to 66,885GWK if the per capita remains in the range of 14880 to 15525. Regression analysis is a set of methods means by which relationship between a dependent variable and an independent variable is estimated. Least square method is a type of regression analysis whereby a best fitting curve or line is found for a set of data points. By finding the relationship between the both variables, a trend of outcome can be estimated. Iterative reweighted least square (IRLS) method is also a type of regression analysis which makes use of an algorithm to carry out the forecast using weighted least square calculations. The algorithm is easy to implement because it makes use of standard regression procedures and a statistical package with command language can easily be used to implement it IRLS is a description of a computational algorithm whereby weighted least square regression steps are repeated with weights and possibly the dependent variable is recalculated each after each cycle. The data which is used for carrying out these studies are usually obtained from different sources. The input as we will see in artificial neural network is very key to the precision of the forecast. Therefore it will be an advantage to test the relation.

**5.2 Modified Forecasting Techniques:**

Modified forecasting techniques are traditional forecasting techniques which have been modified to automatically correct parameters in forecasting models in a dynamic environmental condition. Examples of these techniques include adaptive load forecasting method, support vector machine based techniques and stochastic time series method. Setiawan et al carried out a study on forecasting the very short electricity demand using support vector regression (SVR). SVR was used to predict the electricity demand every 5 minutes based on the data collected from the Australian electricity operator, National Electricity Market Management Company Limited (NEMMCO) for a period of 2 years. Support vector regression is a type of Support Vector Machine algorithm which is used for forecasting. It uses optimization method to find the maximum margin hyper plane between different sets of data. The decision boundary is defined by a set of data which are called the support vector. Back propagation neural network which is a common forecasting method used by industry forecaster was compared with this method. Also simple linear regression and least mean square methods were also used. The result obtained revealed that the support vector method was more promising than the other forecasting methods which were compared with it. Support vector machine was applied by Kaynar et al [29] to forecasting the electricity demand for Turkey. Turkey is a country that depends on other nations for its energy supply which means any external political or economic forces can affect the energy supply chain positively or negatively and this can affect the stability of the country. This instability directly affects electricity demand. Turkey has an expected annual growth of 1.6% and this directly affects the economic growth. Also, since turkey imports energy resources to meet its energy needs, it was important to consider import and export while carrying out the forecast. The study was done using data from electricity consumption, population, import and export data ad GDP collected for the period of 1975-2014. 60% of the data collected was used to train the algorithm while 40% was used to test it. The study also applied chaotic particle swarm optimization algorithm to determine the parameters used by SVR to improve its accuracy. Chaotic particle swarm optimization (CPSO) technique is a computational method which solves a problem optimally by iteratively attempting to improve a candidate solution with respect to a given standard. It is basically an optimization technique which contributes to a solution by ensuring it provides the best possible solution. Combining both SVR and chaotic method was found to provide a simple and effective forecast while improving the accuracy and quality of the forecast in many studies. The result from their study proved that the combination of SVR method and CPSO was very effective giving an error performance of 1.46%. They concluded that this method can be used as an alternative to traditional regression and artificial neural networks. Further study on support vector machine was carried out by Kuching et al [30] on energy demand in Tanzania. They applied Pearson VII universal kernel (PUKF-SVR) which was proposed by Karl Pearson in 1895.

This method is a special case distribution which was proposed noting that all distributions do not resemble the normal distribution. Kernel based algorithm was included to transform the data to a higher dimension. This will enable the problem to be solved as if the feature space was linear separable. Annual data was collected for a period spanning 1990 – 2011. The dataset collected included population, GDP, per capita energy consumption, total energy supply, gross national income per capita, electricity generation and emission data. Three variables; economic, energy and environment were selected as the indicators of the study. This selection was made to determine the influence of these indicators on the forecasting of energy demand in Tanzania. The study compared the result from the PUKF-SVR with normalized polynomial-SVR, polynomial –SVR and RBF-SVR to ascertain the most accurate method. Root mean squared error (RMSE), correlation coefficient (CC), mean absolute error (MAE), root relative squared error (RRSE) and relative absolute error (RAE) were the performance indices used to evaluate the estimating capabilities of all the methods tested. The results obtained showed that polynomial – SVR had the most accurate forecast. A study was carried out to compare different regression techniques used in forecasting electricity demand in Queensland, Australia. Mohamed et al [used Multivariate adaptive regression spline (MARS), support vector regression (SVR) and autoregressive integrated moving average (ARIMA) to carry out the study. Half hour electricity data was acquired for a period between January 2012 to December 2012 for the purpose of the study from the country's energy market operators. Partial correlation data was applied to the historical data to prepare the data for the MARS and SVR models while single input historical data was used to develop the ARIMA model. The data acquired were divided into two parts; the first part which is 80% was used for training the model while the remaining 20% was used for testing the model. The results obtained was tested for error using root mean square and mean absolute error and Pearson product moment correlation coefficient. The results obtained showed that for the half hour and one-hour short term forecast, the MARS model performed better than the other models while for the daily (24 hours) forecast, the SVR model performed better than the MARS and ARIMA models. The study concluded that the MARS and SVR model were more suitable for short term forecasting of electricity demand given the set of data used. Hong proposed the use of support vector regression to forecast the Taiwan regional electricity load. The SVR model is combined with the novel immune algorithm (IA) to determine three parameters in the SVR model. Support vector machines was initially proposed by Vapid. Support vector machines (SVM) solve classification problems by transforming them to convex optimization problems. SVM is transformed to SVR by introducing a region around the function called the an e- tube. Immune algorithm was proposed by Mori et al. Immune algorithm is designed to mimic the learning mechanism of the natural immune system. Immune Algorithm (IA) imitates the behavior of our observed immune functions, principles and mechanisms to solve complex optimization problems. Combining both the support vector machines (SVM) and Immune algorithm (IA) produced the support vector regression immune algorithm (SVRIA) method being proposed. The performance of the SVRIA forecasting method was compared with three other methods; SVM model with genetic algorithm (SVGM), Artificial neural network (ANN) and regression models. MAPE was used to measure the performance of different forecasting results obtained from the methods used in this study. The result showed that the SVRIA model performed beater than the other models. Adaptive demand forecasting is another forecasting method. Adaptive demand forecasting is a method whereby model parameters are automatically updated with the changing load conditions. Demand forecasting is adaptive in nature as conditions normally change in real life. In this method, the next state vector is estimated by using the current prediction error and the current weather data from acquisition projects. The state vector is determined by analyzing the historical data gotten. Load demand forecasting using time series stochastic method was used by Salah et al to forecast the electricity demand in Libya. Time series method is a type of quantitative forecasting method. The other type of quantitative forecasting methods is the associative models. The time series method use past data patterns and attempts to predict the future while associative models assume that the variable being forecasted has a relationship with other variables and tries to forecast using the relationships. Time series is further divided into two types namely deterministic and stochastic time series.

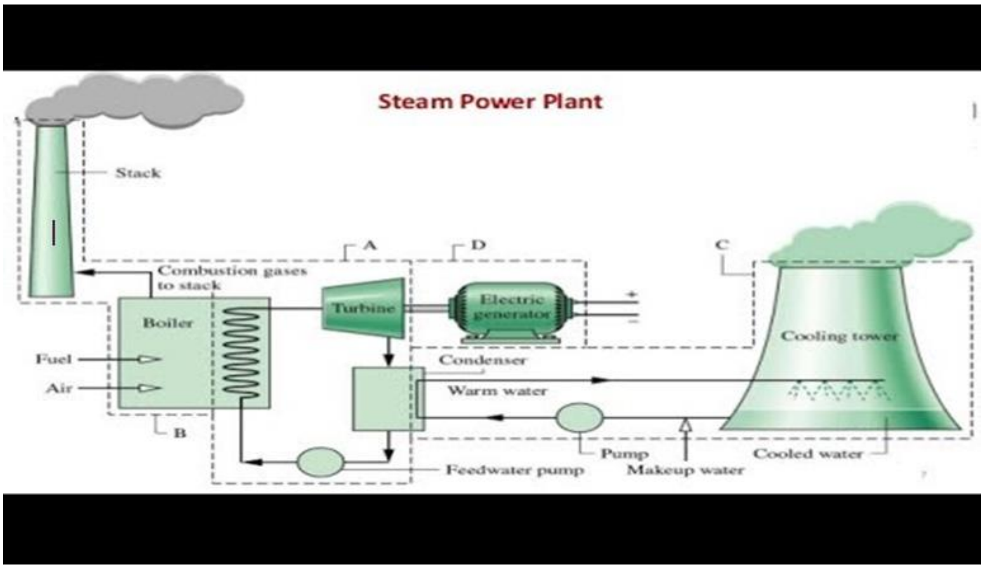



Figure 5.5: Steam Power Plant.

Data was collected for the work from 2000-2010. To carry out the study, ARIMA model was identified by creating a time series plot on a Cartesian coordinate and analyzing it if there is a stationary mean and variance or not. The model was tested for accuracy using MSE. The time series forecast revealed that there will be continuous growth of demand of oil and electricity which will lead to an increase in cost of energy due to rapid population growth. The results were used to provide information for an alternative policy option in their market. Nogales, et al used two-time series methods (dynamic regression and transfer function models) to forecast the electricity demand. The study proposed the use of these two time-series methods in forecasting the next day pricing for the electricity market in Spain and California. The data used for the forecast was collected between June 1st 2000 to august 20th 2000 and this data was used to forecast and validate the period selected (21st to 27th of august and November 13th to 19th, 2000).

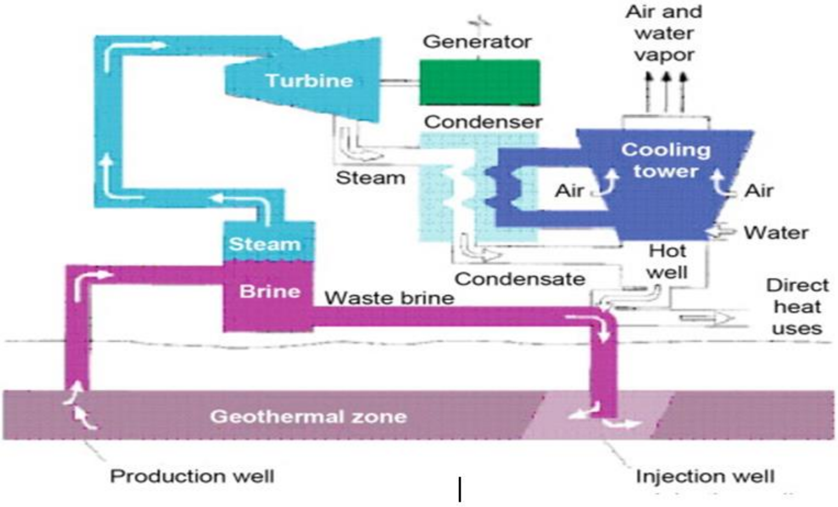



Figure 5.6: Steam Power Plant**.**

The same was done for the California electricity market; data was collected from January 1, 2000 to April 2, 2000 to forecast and validate the period selected for the study. The results of the forecast for the Spanish and California market was obtained as approximately 5% and 3% respectively for the weeks studied. The error shows that the forecast can be used since they fall within the acceptable range. There were some observations made from the forecast of the Spanish market; The Spanish market had a higher proportion of outliers and it also showed high dispersion which led to the conclusion that the Spanish market was less predictable and less accurate. Support vector method has shown greater promise when combined with other methods. Hong et al used support vector regression with seasonal adjustment mechanism (SSVRCIA) combined with immune algorithm to carry out the monthly load forecast. Chaotic immune algorithm is modeled after the biological immune mechanism using mathematics and combines chaos operators with immune algorithm. The concept of immune algorithm is new. It learns from the concept of immunity in life science. They considered the seasonal component of electric energy demand caused by seasonal fluctuations. A new method combining support vector regression (SVR) and hybrid chaotic immune algorithm (CIA) was proposed by Hong et al to forecast the seasonal load demand. This method known as the support vector regression with hybrid chaotic immune algorithm (SSVRCIA)was applied to investigate its application in forecasting electric load.

The results from the SSVRCIA method were compared with some other methods e.g., ARIMA and e-insensitive loss function support vector regress - TF-ε-SVR-SA and SVRCIA method. An analysis of all the methods used showed that the SSVRCIA method performed better than all the other methods used in the study. SSVRCIA method resulted in a mean absolute percentage error (MAPE) of 1.766% and it was had the lease error when compared to the other methods. Azad et al carried out a study on predicting the future peak load demand based on historical data. Support vector regression was selected for predicting the peak load demand due to its structural risk minimization principle that minimizes the upper bound of the generalization errors. The study was conducted by collecting the temperature and relative humidity for three consecutive years (between 2014 to 2016) in the city of Sharjah, UAE. UAE has moderate winter and very hot summer seasons. The hot summers leads to a surge in electricity demand due to high power consumption for air conditioning units. This weather condition affects the electricity demand as such it is very important during a forecast. The data collected in the first 2 years was used in training the SVM while the data of 2016 was used to test the model by comparing with the actual peak load demand in order to verify the accuracy of the model. SVR produced an excellent result for both the electricity demand weekend data and seasonal data applied. To further verify the accuracy of support vector machines (SVM), Mohandes applied support vector machines to short term load forecasting and compared the result with autoregressive (AR) modeling. The results from the SVM and AR were tested using root mean square error (RMSE). SVM produced 0.0215 while the AR model was 0.0376. Abbas and Arif utilized support vector machines optimized by genetic algorithm to forecast daily peak load long range demand. The load demand data was collected every half hour for this study was for a period from January 1997 to December 1998and also the daily temperature data was collected for the same period. Data collected from the period of January 1997 to December 1997, and February 1998 to December 1998 was used for training. The proposed algorithm emerged as the best model when compared to other methods. Deng and Jirutitijaroen used two-time series methods; multiplicative decomposition and the seasonal ARIMA model to forecast the short-term electricity demand for Singapore. The multiplicative decomposition data has a mathematical expression with a cyclic component which is applied for long term forecast. Since range of the forecast is a short term, the expression is modified for this study to exclude the cyclic component. The results obtained from the forecast showed that the decomposition model is more accurate than the seasonal ARIMA model. The lowest value from the forecast using MAPE was 0.761% for the multiplicative decomposition method while 4.8045% for the seasonal ARIMA method. Saguache and Chekov applied time series regression to carry out a short term forecast of South African electricity demand. Data was acquired for a period of 10 years between 2000 to 2010 for this study. The study evaluated the effect of temperature on the peak electricity demand. Three different time series regression models were applied to the data in this study. The results revealed that the time series model with the temperatures included through regression splines performed better than the model which used heating and cooling degree days. Taylor et al carried out a research to find the univariate forecast using half hourly data in England and Wales. Electricity load data collected at half-hourly basis would reveal more than one pattern. Within a 24hour cycle, there would be peak demands due to the time of the day, ambient fluctuations due to weather etc. The work conducted proposed the use of multiplicative seasonal ARIMA model and double seasonal holt-winters exponential smoothing method which are able to capture within day and within week seasonal influences on load demand. The multiplicative seasonal ARIMA model can be modified to accommodate three or more patterns by introducing additional polynomial functions. The Holt-Winters method is applied where there are two or more seasonal patterns in the time series. The proposed multiplicative seasonal ARIMA method outperformed the standard Holt-Winters method for forecasting. Double seasonal Holts-Winters method also outperformed the standard holt-winters methods as observed by the results obtained. Soft Computing Technique: Soft computing technique is a new technique which is used to mimic the ability of a human mind to reason out and learn when placed in an environment of uncertainty. They are usually applied when the system which is to be forecasted is uncertain and very hard to model precisely. Soft computing forecasting techniques include fuzzy logic, neural networks, and evolutionary algorithms like genetic algorithm. Ashigwuikeet al, compared artificial neural network with multiple regression technique. They carried out the study using data of monthly load from Abuja municipal area council, Nigeria. Data was obtained from 2012 to 2018 from the Abuja electricity distribution company for this study. Average growth rate was extrapolated from the world population site to calculate the average population for the year 2018 to 2020 in Abuja. In addition to the population, ambient temperature was collected from 2012 to 2018 for this study. The results of the forecast obtained were tested with MAPE and R-value deviation for accuracy. The results obtained for the artificial neural network showed an average of 0.00197 error when applying mean absolute percentage error calculation (MAPE) and the multiple linear regression had a value of 0.004545. For R-value deviation, ANN was 8.06% while multi linear regression (MLR) was 34.42%. Artificial neural network (ANN) is a fascinating new field. It is a replication of the human brain and has the ability to learn new things, adapt to new environment and situations. Using ANN for forecasting is one of the many applications of the method which has gained much acceptance in recent years. An artificial neural network consists of nodes or processing units called neutrons. Each neutron has a function attached to it. Some advantages of ANN are that it is adaptive, it is self-tolerant and it can accommodate fault. ANN was applied by Akarslan and Hocaoglu to carry out a short term electricity demand forecast of a campus area.

### 5.3 Disadvantages

- Relatively high overnight cost.
- Steam turbines are less efficient than reciprocating engines at part load operation.
- They have longer startup than gas turbines and surely than reciprocating engines.
- Less responsive to changes in power demand compared with gas turbines and with reciprocating engines.
- Air pollution from smoke fumes.
- Costs more to run compared with other types of power stations.

**Chapter -6**

# Results & Discussions

### 6.1. Applications

Steam engines can be said to have been the moving force behind the Industrial Revolution and saw
Wide spread commercial use driving machinery in factories and mills, powering pumping stations and transport appliances such as railway locomotives, ships and road vehicles.

- Military: Steam tank (tracked), Steam tank.
- Road: Steam wagon, Steam bus, Steam tricycle,
- Construction: Steam roller, Steam shovel
- Agriculture: Traction engine, Steam tractor

### 6.2. DISCUSSION

It would be interesting to have the views of some gas engine advocates in respect to the B.t.u. consumption obtained in the tests as compared with what they would expect under similar conditions for a gas-engine plant. The figures would indicate that the B.t.u. consumption per kw-hr. is low as was also the case in the tests of the oil-burning plant at Redondo, Cal., the results of which have already been reported to the Society. In these tests a kilowatt-hour was turned out at the switchboard with a consumption of about 25,- 000 B.t.u., based on the total heat of combustion of the fuel burned, all the oil burned for miscellaneous purposes about the plant being included, as well as that for carrying the boilers over a 4| hr. layover period. C h a s . H. Parker1 and I.E. Moul trop . Referring to Mr. Varney's paper, it is interesting to learn that the steam turbine has operated satisfactorily when compared with a large number of water power stations and its service has been more satisfactory in regulation and maintenance than that obtained from either steam engines or gas engines. The engineers of the Pacific Gas and Electric Company are to be congratulated on the speed with which a 9000-kw. steam generating station was completely built and also on the very low cost of this station per kilowatt of capacity. If Mr. Varney will state briefly in his closure how this very low cost was obtained it will add much interest to his paper. The author states that the test showed the water rate of the turbine to be inside the manufacturer's guarantee, but it would seem that the actual performance was not especially creditable to a modern Curtis turbine of 9000-kw. Maximum capacity. Of course, the vacuum during the test was not especially good and with injection water of 51 deg. to 52 deg. fahr., it should be possible to reduce the absolute back-pressure reported in the test by about 1 in., which would improve very much the water rate of the turbine. The superheat of 70 deg. to 75 deg. on the maximum load test is also rather low for the best results. Experience has proved that 150 deg. fahr. of superheat is safe for super heaters and piping and this increased quantity would better the water rate some 6 per cent,. Either or both of these changes might have increased the investment by a small amount.* However, a gain of about If lb. in the water rate per kw-hr. would seem to be easily obtainable and would justify.

In this micro turbine design using Solid works and Consul Multiphasic analytical software, the results obtained mainly covered the blade, shaft and nozzle design. In blade design parameters, stress failures, efficiency and inlet/outlet angle were considered and the outcome is illustrated in. In casing volume design, the overall heat transfer in the volume and mean temperature different concepts were analyzed. The outcome of the stress analysis of the blade in withstanding the forces. The outcome interface of thermally induced stress on the turbine stator blade is presented in. The thermal stress on the analyzed stator shows that the heat distribution in the stator, represented by color gradients indicated red as the highest thermal stress temperature of 6.018e+002 K under COMSOL metaphysics analysis. This shows that the stator cannot be majorly affected by heat or overheated in the turning process when operated within the temperature 5.231e+002 K and 6.018e+002 K. The result of the thermal analysis carried out on the stator shows that the stator cannot be affected by heat, stress and strain during torsion/compression process with a strain tolerance ranging from 1.46008e-012 to 1.86427e-008. The stress/heat analysis outcome on the turbine rotor and blades indicated allowable heat load/temperature of 250˚C with maximum heat flux of 200 W/m2. Heat load beyond the stated allowances open the design to imminent failure. The modified flow conditions adopted has led to variation in efficiency of the stator profile. The least efficiency (40%) was found with the modified airfoil on stator and rotor, while the rotor axial chord reduction had the highest efficiency (75%) as compared with the stator count and stator axial chord reductions with relative blade performance shown in Figure 10. Comparing the recorded stresses and yield strength of the materials of the components, a wide margin was observed, which means that the components will serve their intended purposes without failure within the allowable margin. It can be inferred, from the result of comparison, that the design is safe under normal working condition (at displacement range of 0 mm to 10.2883 mm) of the shaft in terms of stress, strain and temperature rise beyond 10.2883 mm displacement the system is bound to fail. The simulated results showed that the design is optimized to perform intended functions without any record of failure. The only point of note was that the shaft must not exceed the maximum deflection of 10 mm under the maximum allowable loading. The danger therein can be averted with improvement in material selection and right choice of loads acting on the system (Table 2). The exploded, assembled, sectioned micro turbine views with their specifications are given in Figures 12-14, respectively. The implementation of the process has enabled realization of the micro turbine that is capable of producing

5 kW of electric power using the superheated steam from PKS fuelled boiler of 5.5 kW capacity, as the prime mover. The components of the turbine and the mini power house can be produced using machining and welding techniques and the materials can be sourced locally (Table 2). The cost of production, inclusive of mini power house, is N590,000 or $1638 in US Dollars (Table 3). The cost of production can be greatly reduced by 50% under mass production regime.

## 6.3 Results

The results given by Mr. Naphtaly in Table 1 under the heading B.t.u. per kw-hr. vary considerably from those which 1 have calculated, and give the turbine a much lower heat consumption than I think it should be credited with. I have tried various methods and have used both the old and the new steam tables but have not been able to check the figures given in the table. Table iii shows the revised results.

Table III: Revised summary of tests on 10,000-kw. Turbine Marks and Davis Tables

| Run | Load, km | Steam Pressure, Lb. Gage | Superheat, Deg. Fahr | Vacuum, 30 In. Bar-ometer | Water per Kw-hr. | B.t.u. per Kw-hr. | Rankine Cycle, Ratio | Thermal Efficiency, Percent |
|---|---|---|---|---|---|---|---|---|
| A | 7972 | 171 | 58 | 28.28 | 14.581 | 17035 | 66.8 | 20.04 |
| B | 8563 | 168 | 59 | 28.18 | 14.427 | 16830 | 68.2 | 20.27 |
| C | 8198 | 169 | 60 | 28.10 | 14.596 | 17017 | 67.6 | 20.05 |
| D | 9173 | 167 | 59 | 27.90 | 14.572 | 16926 | 68.0 | 20.15 |
| E | 5333 | 173 | 54 | 28.34 | 15.655 | 18274 | 61.8 | 18.67 |
| F | 8148 | 167 | 60 | 26.16 | 15.855 | 18093 | 69.5 | 18.86 |
| G | 5401 | 174 | 56 | 26.16 | 17.611 | 20075 | 62.2 | 16.99 |

The heat consumption of a turbine is the difference between the heat content of the entering steam and the heat of the liquid in the exhaust steam, multiplied by the pounds of steam per kilowatt-hour. Accordingly, for run B, with 168 lb. gage pressure, 59 deg. superheat, 28.18 in. vacuum and 14.427 lb. steam, we get a heat consumption of (1232.7-66.1) 14.427 or 16,830 B.t.u. per kw-hr. This result is almost 12 per cent higher than that given by Mr. Naphtaly. The corresponding thermal efficiency is 20.27 and not 22.65 per cent. Mr. Naphtaly's figures for Rankine cycle ratio check very closely with those which I have calculated. 1 Student Mem. Am. Soc. M.E., Cornell University. Presented at the Annual Meeting, New York 1910, of The American Society of Mechanical Engineers.

### 6.4 Efficiency of steam engine

A steam engine is a type of heat engine. It takes heat from the hot steam, converts some of this heat into useful work and dumps the rest into the colder surrounding air. The maximum fraction of heat that can be converted into work can be found using the laws of thermodynamics, and it increases with the temperature difference between the hot steam and the surrounding air. The hotter the steam and the colder the air, the more efficient is the steam engine at converting heat into work.

In a typical steam engine, a piston moves back and forth inside a cylinder. Hot, high-pressure steam is produced in a boiler, and this steam enters the cylinder through a valve. Once inside the cylinder, the steam pushes outward on every surface, including the piston. The piston moves. The steam does mechanical work on the piston and the piston does mechanical work on the machinery attached to it. The expanding steam transfers some of its thermal energy to this machinery, so the steam becomes cooler as the machinery operates. When the piston reaches the end of its range, the valve stops the flow of steam and opens the cylinder to the outside air. The piston can then return easily. In many cases, steam is allowed to enter the other end of the cylinder so that the steam pushes the piston back to its original position. Once the piston is back at its starting point, the valve again admits high-pressure steam to the cylinder and the whole cycle repeats. Overall, heat is flowing from the hot boiler to the cooler surrounding air and some of that heat is being converted into mechanical work by the moving piston.

The maximum efficiency of a steam engine is emax = (Tsteam - Tair)/Tsteam.
The actual efficiency is usually much lower.
That is the maximum possible efficiency of a steam engine taking in heat at 160 degree Celsius and dumping it at room temperature of approximately 20 degree Celsius
Reasoning:
The maximum efficiency of any heat engine is that of a Carnot engine. emax = (Thigh - Tlow)/Thigh.
the calculation:
160 degree Celsius = 433 K and 20 degree Celsius = 293 K.
The maximum possible efficiency is
(Thigh -T Low)/Thigh = (433k – 293k)/433k = 0.32 = 32%.

For the case of going from 377C to 90C. The Rankin cycle ratio of 0.4 is proven for simple steam engines - so our worst-case efficiency scenario is 17.6%. If we subtract 10% from this for mechanical efficiency losses - then we obtain about 16% efficiency. We can approach the triple expansion engine efficiency. 6 Ranking cycle ratio - or steam engines with 26.4% thermal efficiency. Cylinder insulation should cover cylinder heat loss, and perfect control of steam injection should allow for near-complete extraction of usable energy from steam.

Now, For power calculations use PLAN/33,000.

where;

P=mean effective pressure in 85

L=length of stroke in feet

A=area of piston in square inches

N=number of power strokes per minute

Now,0.5" bore, a 6" stroke, a speed of 90 rpm, and a boiler pressure of 150 lbs., the size of the 50 horse-power Case engines.

P = 85 lbs.

L = 6 / 12 or 0 .5 feet.

A = 2 x {3.1416 x (0.5)2 }+ {2 x 3.1416 x 0.5 x 6} = 20.4204 sq. in.

N = 90 x 2 = 180 strokes per minute. (That is, 180 working strokes per minute.)

Substituting these values for the letters in the formula above, it becomes:

85 x 0.5 x 20.4204 x 180

---------------------------- = 4.15 horse-power

33000

Torque

Much less steam was admitted to the cylinder and it is leaving at far lower pressure; both of these indicatives of more efficient operation. Therefore, a steam engine can produce great torque, at low efficiency or much less torque at higher efficiency.

The torque calculation for a steam cylinder connected to a crank at 90degrees rotation is, force times arm. 1413.7 of force X .125ft arm (3" stroke / 2) = 176.7 lbsft torque There are three things working against the efficiency of a steam locomotive. One is that it is a non-condensing cycle. Condensing is not very practical in a steam locomotive as you are not carrying a cooling pond with you, and the few instances of condensing locomotives (South Africa had some) had limited efficiency gain owing to the inefficiencies of an air-cooled condenser. A second is the low boiler pressure, and that in part is tied to the non-condensing cycle.

**Chapter** -7

# CONCLUSIONS

## 7.1 Conclusions:

After analyzing the calculations and observations we are able to deduce for a fact that the solution obtained is commercially viable and can be put to effect. As the rates of electricity are going up in the newest revision, the solution becomes more attractive. The costs of electricity considered in this paper are current and not the revised ones. This situation of rising rates of electricity can be used as a profitable business idea by selling the excess to the grid or any potential consumer. As there is no standardization in the manufacturing of steam turbines, the turbine can further be developed to harness the full potential of the system. lectricity demand forecasting is an essential part of the electricity industry. From the planning of electricity generating plants, expansion of electricity supply network, policy making, electricity market analysis and many more reasons electricity demand forecasting provides enough data to make calculated and informed decision. Several methods have been researched on for electricity demand forecast. Each method has its advantages and disadvantages depending on the available data and the peculiarity of the country where the data is acquired. Over the years, Nigeria has failed to plan for electricity supply. Some of the reasons for this are political, others are infrastructural, economical and on a lighter note, one would add spiritual. Forecasting is a tool which helps with planning into the future. Different techniques have been proposed for this purpose by different researchers and they have different advantages depending on which one is applicable given the situation. Techniques that are adaptive and accurate like artificial neural network are beneficial for forecasting in a situation where there is indirect relationship between the dataset. Making use of forecasting techniques will provide enough information for making informed decision that will help Nigeria meet the its growing electricity need. In addition to the planning of electricity demand into the future, forecasting of electricity demand in Nigeria will help to plan for natural gas sustainability. Natural gas is limited and found in large deposits abundantly in Nigeria. Nigeria depends majorly on exportation of energy resources to sustain the economy and also relies on this same energy resources for its electricity needs. Accurate determination of electricity demand will aid in determine the gas consumption in the future. In this study, thermoeconomic analysis has been applied to a steam power plant. The analysis has been done with MATLAB computer program. The optimum operating values for a 500 MW steam power within the stated design parameters has been defined as $900^0$ C boiler temperature and 250 kg/s steam flow. With these values, the unit cost of steam is 0,538 $/MW and the unit cost of electricity is 1,18 $/MW. The cost of electricity is approximately twice more than steam cost. Besides, it has also been seen that due to the rise in boiler temperature, the unit cost of steam and the unit of electricity has increased. The results obtained from this study will significantly contribute to the application of an actual steam power plant to be practiced.

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