Basic Phenomenon of Power Plant and Its Protection System

An internship report submitted to the Department of Electrical & Electronic Engineering (EEE), (Sonargaon University) for partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical & Electronic Engineering.

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CERTIFICATE

This is to certify that, Abdul Al Manun. ID: EEE-1403003114 has successfully completed their project entitled **“Basic Phenomenon of Power Plant and its Protection System”** under my guidance and direct supervision this project is submitted for the partial fulfillment of the requirement for the degree of B.Sc. in Electrical & Electronic Engineering from the Department of Electrical & Electronic Engineering of Sonargaon University.

The thesis represents an independent and original work on the part of the candidates. The research work has not previously formed the basis for the award of any degree, diploma, fellowship or any other discipline.

The whole work of this thesis has been planned and carried out by this group under supervision and guidance of the faculty members of Sonargaon University.

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DEDICATION

To Almighty ALLAH and Our Respective Parents

ACKNOWLEDGEMENT

All praise of almighty Allah who is merciful, with His kindness & blesses the topic of this project is going to be completed.

At first we would like to express my gratefulness, indebtedness & gratitude first to our supervisor **Md. Habibur Rahman** (lecturer EEE) for giving us the opportunity to work under his supervision, the endless hours of help, suggestions, advice and support to keep us on track during the development of this thesis& inspiration to achieve our goal.

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We also give thanks to technician, laboratory staffs & others of EEE Department, SU for their help throughout my stay at SU

Last, but not least, we would like to thank our parent and family for making it possible for us to study and for their constant help and support.

Finally, I convey thanks to my friends for peaceful co-operation.

Abstract

Basic Phenomenon of Power Plant and Its Protection System

The important consideration of theory and practical base study **Basic Phenomenon of Power Plant and Its Protection System** In this study we consider the electrical energy that produced in the generating station and control generated power and transmission of power from one place to another and finally the power distribution among the consumers. The operation of electric power distribution systems and associated major apparatus are presented. the content include principles of power system, cabling systems, electrical power system protection and coordination, instruments and meters, operational procedure and electrical utilization systems. Actually transmission line is a part of distribution system and line loss is also taken to consideration

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History of Power Plant

1.1History of power plant

1878. The station consisted of 24 dynamo electric generators which were driven by a steam engine. It was used to illuminate a grotto in the gardens of Linder of Palace.

The first public power station was the ***Edison Electric Light Station***, built in London at 57, Holbein Viaduct, which started The world's first power station was built by Sigmund chucker in the Bavarian town of Etta and went into operation in operation in January 1882. This was an initiative of Thomas Edison that was organized and managed by his partner, Edward Johnson. A Babcock and Wilcox boiler powered a 125 horsepower steam engine that drove a 27 ton generator called Jumbo, after the celebrated elephant. This supplied electricity to premises in the area that could be reached through the culverts of the viaduct without digging up the road, which was the monopoly of the gas companies. The customers included the City Temple and the Old Bailey. Another important customer was the Telegraph Office of the General Post Office but this could not be reached though the culverts. Johnson arranged for the supply cable to be run overhead, via Holbein Tavern and New gate.

In September 1882 in New York, the Pearl Street Station was established by Edison to provide electric lighting in the lower Manhattan Island area. The station ran until destroyed by fire in 1890. The station used reciprocating steam engines to turn direct-current generators. Because of the DC distribution, the service area was small, limited by voltage drop in the feeders. The War of Currents eventually resolved in favor of AC distribution and utilization, although some DC systems persisted to the end of the 20th century. DC systems with a service radius of a mile (kilometer) or so were necessarily smaller, less efficient of fuel consumption, and more labor intensive to operate than much larger central AC generating stations.

AC systems used a wide range of frequencies depending on the type of load; lighting load using higher frequencies, and traction systems and heavy motor load systems preferring lower frequencies. The economics of central station generation improved greatly when unified light and power systems, operating at a common frequency, were developed. The same generating plant that fed large industrial loads during the day, could feed commuter railway systems during rush hour and then serve lighting load in the evening, thus improving the system load factor and reducing the cost of electrical energy overall. Many exceptions existed, generating stations were dedicated to power or light by the choice of frequency, and rotating frequency changers and rotating converters were particularly common to feed electric railway systems from the general lighting and power network. Sand relying on interconnections of multiple generating stations to improve reliability and cost. High-voltage AC transmission allowed hydroelectric power to be conveniently moved from distant waterfalls to city markets. The advent of the steam turbine in central station service, around 1906, allowed great expansion of generating capacity. Generators were no longer limited by the power transmission of belts or the relatively slow speed of reciprocating engines, and could grow to enormous sizes. For example, Sebastian Zane de Ferranti planned what would have been the largest reciprocating steam engine ever built for a proposed new central station, but scrapped the plans when turbines became available in the necessary size. Building power systems out of central stations required combinations of engineering skill and financial acumen in equal measure. Pioneers of central station generation include George Westinghouse and Samuel Insula in the United States, Ferranti and Charles Hester man Mere in UK, and many others.

1.2 Demand of electricity skyrockets

Global energy demand would not stop to increase and will be about 30 percent bigger in 2040 compared to 2010, as economic output more than doubles and prosperity expands across a world whose population will grow to nearly 9 billion people (Exxon Mobile, 2013) and over 1.3 billion people are suffering from lack of basic electricity (IEA, 2012). Therefore we cannot evade the permanent electricity supply problems with disregarding the facts.

Sustainability

Environmental sustainability has become a core issue for human societies throughout the world. So sometimes we are forced to choose policies of many different fields in the perspective of sustainability (OECD, 2008). These trends let us think more about sustainability of energy sources including nuclear power. But current energy's sustainable are threatened with population growth and energy demand increase. The decisions whether keeping nuclear or phasing out will be decided by each countries authority considering their economic, politic, environmental conditions and so on.

Efforts to find smart answers for energy problems

Nowadays, more and more academic and political interest has been concentrated on the matter of sustainable and we try to meet energy demands and to mitigate the threat of climate change – two of the 21st century's greatest challenges – there are major opportunities for expansion of nuclear energy in those countries that choose to have it. But those opportunities also pose complex and broad-ranging safety and security questions that must be addressed effectively (IAEA, 2008). However if we develop some guides for countries to help decide their nuclear power policy from the point of view of sustainability more and more countries could find it easier to identify their best options (Hausa-DeLay, 2011)..

Current status of nuclear power

From table 1, we can see about 11% of global electricity is generated by 440 nuclear power reactors in 32 countries, there are 36 units currently under construction in 14 countries (IAEA, 2012). The first commercial nuclear power reactor began operation some 40 years ago, with a rapid expansion in reactor units taking place during the 1970s and early 1980s.

From 1990 to 2012, nuclear power expanded steadily until 2006 and fluctuated with small range but the proportion of nuclear in world electricity production continues to decrease from 14% to 11% and after 2005, nuclear power lose its increasing state (Mycale Schneider, 2013). This may mean that the popularity of nuclear power to human may decline.

A power station (also referred to as generating station or power plant) is a facility for the generation of electric power. 'Power plant' is also used to refer to the engine in ships, aircraft and other large vehicles. Some prefer to use the term energy center because it more accurately describes what the plants do, which is the conversion of other forms of energy, like chemical energy, gravitational potential energy or heat energy into electrical energy. At the center of nearly all power stations is a generator, a rotating machine that converts mechanical energy into electrical energy by creating relative motion between a magnetic field and a conductor. The energy source harnessed to turn the generator varies widely. It depends chiefly on what fuels are easily available and the types of technology that the power company has access to.

1.3 Classification of Power plants

Power plants are classified by the type of fuel and the type of prime mover installed.

By fuel

- In Thermal power stations, mechanical power is produced by a heat engine, which transforms thermal energy, often from combustion of a fuel, into rotational energy
- Nuclear power plants use a nuclear reactor's heat to operate a steam turbine generator.
- Fossil fuel powered plants may also use a steam turbine generator or in the case of Natural gas fired plants may use a combustion turbine.
- Geothermal power plants use steam extracted from hot underground rocks.
- In integrated steel mills, blast furnace exhaust gas is a low-cost, although low-energy-density, fuel.
- Waste heat from industrial processes is occasionally concentrated enough to use for power generation, usually in a steam boiler and turbine.

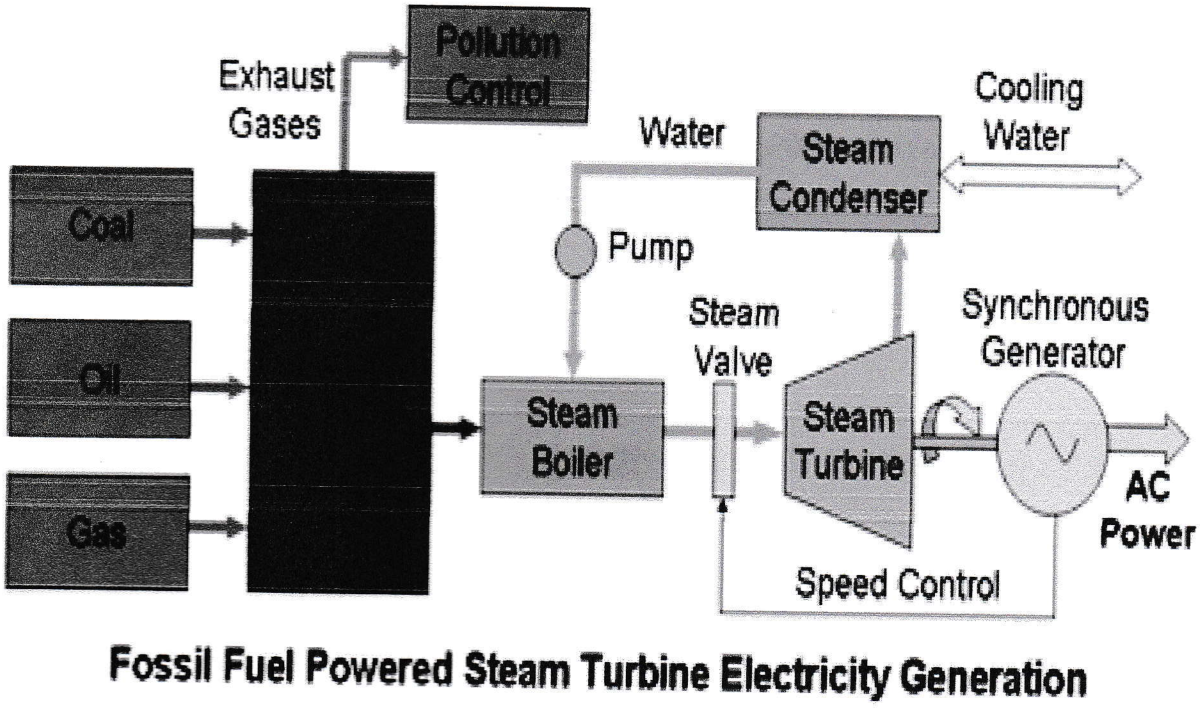


Fig: 1.1 Fossil Fuel Powered steam turbine electricity generations.

1.4 Advantages of Gas Power Plant

- It is a known technology;
  easier than alternative fuels to build power station;
  very responsive - can kick in fairly quickly to compensate for other less reliable energy sources (e.g. wind power) or in times of high demand;
- Fuel requires no pre-processing and no special disposal safeguards;
  fuel is currently readily available;
  - Relatively cheap fuel
  - The initial capital cost of the plant is much lower than say, a nuclear power plant gas power stations do not have the security implications of nuclear power plants.

1.4.1 Benefits of gas power plants

- Stepwise investment with smaller risks and optimized profit generation
- Excellent plant availability and reduced need for backup capacity due to multi-unit installation
- Net plant electrical efficiency of over 44%
- Full plant output at high altitudes and in hot and dry ambient conditions
- High part-load efficiency
- Fast start-up, 5 min from hot standby to full plant load
- Minimal water consumption with closed-circuit radiator cooling
- Low gas fuel pressure requirement
- Maintenance schedule independent of the number of starts or trips

1.4.2 Advantages of gas turbine engines

- Very high power-to-weight ratio, compared to reciprocating engines;
- Smaller than most reciprocating engines of the same power rating.
- Moves in one direction only, with far less vibration than a reciprocating engine.
- Fewer moving parts than reciprocating engines.
- Greater reliability, particularly in applications where sustained high power output is required
- Waste heat is dissipated almost entirely in the exhaust. This results in a high temperature exhaust stream that is very usable for boiling water in a combined cycle, or for cogeneration.
- Low operating pressures.
- High operation speeds.
- Low lubricating oil cost and consumption.
- Can run on a wide variety of fuels.

1.4.3 Disadvantage

Nuclear power plants

- The number one problem of nuclear power is the radioactive waste. The waste from nuclear energy is extremely dangerous and it has to be carefully looked after for several thousand years (10'000 years according to United States Environmental Protection Agency standards). There are not really any solutions to this problem, except for nuclear waste treatment.
- It is a high risk power supply. Of course a nuclear power plant has a very high security standard, but it is impossible to build a plant with a 100% security. We all know what horrible consequences there will be if an error or accident occurs in this plant.

Thermal power plants

- It pollutes the atmosphere due to production of large amount of smoke and fumes.
- It is costlier in running cost as compared to hydroelectric plants.

Solar power plants

Solar power plants require a large area of land to efficiently absorb solar energy. These plants are only as effective as the amount of solar energy they can absorb. This means that certain locations where there is less sun are workable for a solar power plant. Areas of the world with high pollution or cloud cover are also not good locations for solar power plants. Some solar power plants may require some use of fossil fuels to power the plant in times of less sun.

Hydroelectric Power Plants

There are many advantages of hydroelectric power plants, but significant disadvantages as well. They can be dangerous to aquatic life and can cause many other environmental concerns.

Although hydroelectric power plants do have some benefits, there are drawbacks to their use as well. There are many environmental concerns in building a hydroelectric power plant, including disrupting local ecology, and displacement of nearby people and animals.

Chapter: 2

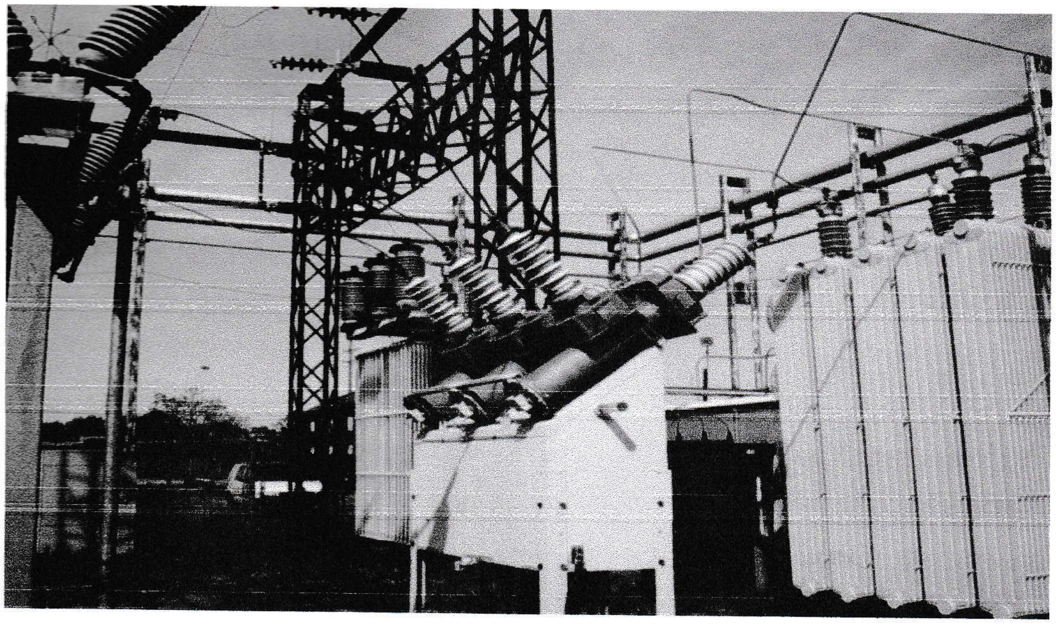
Components of Switch Gear & Protective Relay

2.1 Basic concepts of Switch Gear

Isolate electrical equipment. Switchgear is used both to de-energize equipment to allow work to be done and to clear faults downstream. This type of equipment is important because it is directly linked to the reliability of the electricity supply.

The very earliest central power stations used simple open knife switches, mounted on insulating panels of marble or asbestos. Power levels and voltages rapidly escalated, making opening manually operated switches too dangerous for anything other than isolation of a de-energized circuit. Oil-filled in an electric power system, switchgear is the combination of electrical disconnects switches, fuses or circuit breakers used to control, protect equipment allowed arc energy to be contained and safely controlled. By the early 20th century, a switchgear line-up would be a metal-enclosed structure with electrically operated switching elements, using oil circuit breakers. Today, oil-filled equipment has largely been replaced by air-blast, vacuum, or SF_6 equipment, allowing large currents and power levels to be safely controlled by automatic equipment incorporating digital controls, protection, metering and communications.

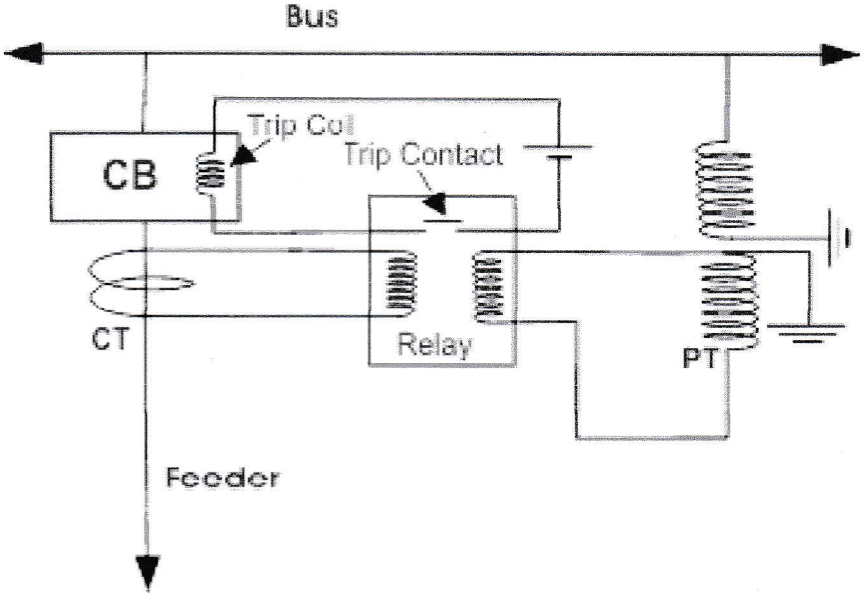
High voltage switchgear was invented at the end of the 19th century for operating motors and other electric machines. The technology has been improved over time and can be used with voltages up to 1,100 kV typically; the switchgear in substations is located on both the high voltage and the low voltage side of large power transformers. The switchgear on the low voltage side of the transformers may be located in a building, with medium-voltage circuit breakers for distribution circuits, along with metering, control, and protection equipment. For industrial applications, a transformer and switchgear line-up may be combined in one housing, called a unitized substation or USS.



2.1 Schematic Diagram of switchgear

2.2 Discussion on Protective Relay

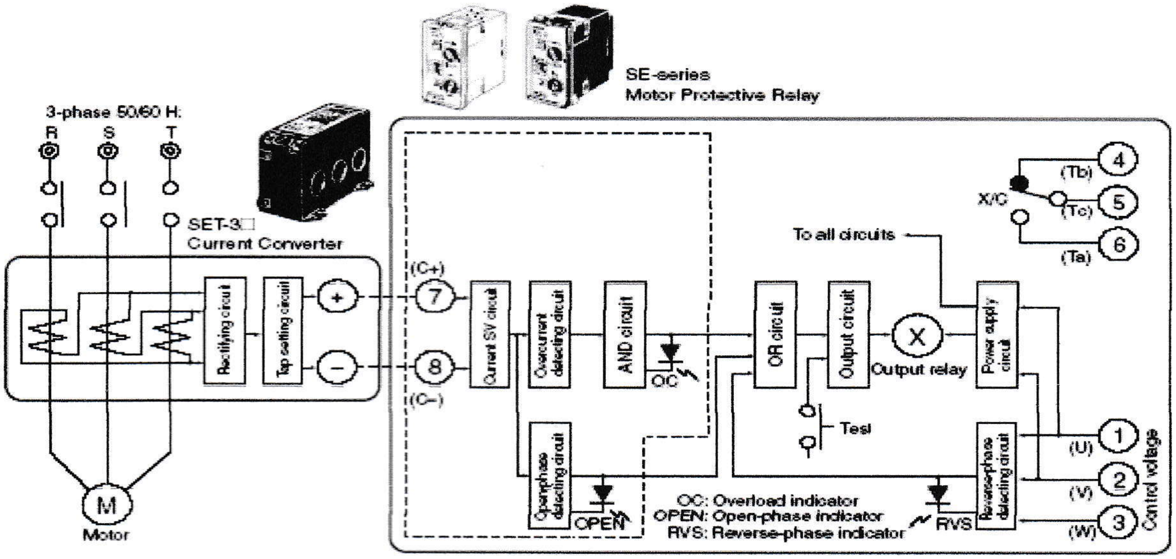
In electrical engineering, a protective relay is an electromechanical apparatus, often with more than one coil, designed to calculate operating conditions on an electrical circuit and trip circuit breakers when a fault is detected. Unlike switching type relays with fixed and usually ill-defined operating voltage thresholds and operating times, protective relays have well-established, selectable, time/current (or other operating parameter) operating characteristics. Protection relays may use arrays of induction disks, shaded-pole magnets, operating and restraint coils, solenoid-type operators, telephone-relay contacts, and phase-shifting networks. Protection relays respond to such conditions as over-current, over-voltage, reverse power flow, over- and under- frequency. Distance relays trip for faults up to a certain distance away from a substation but not beyond that point. An important transmission line or generator unit will have cubicles dedicated to protection, with many individual electromechanical devices. The various protective functions available on a given relay are denoted by standard ANSI Device Numbers. For example, a relay including function 51 would be a timed over-current protective relay.



Basic connection diagram of protection relay

Fig: 2.2 Protective Relay

The theory and application of these protective devices is an important part of the education of an electrical engineer who specializes in power systems. In new installations, these devices are nearly entirely replaced with microprocessor-based digital protective relays (numerical relays) that emulate their electromechanical ancestors with great precision and convenience in application. By combining several functions in one case, numerical relays also save capital cost and maintenance cost over electromechanical relays. However, due to their very long life span, tens of thousands of these "silent sentinels" are still protecting transmission lines and electrical apparatus all over the world.



2.3 Classification of Protective Relay

Protection relays can be classified in accordance with their construction, the incoming signal and function.

2.3.1 Construction

- electromechanical
- solid state
- microprocessor
- numerical
- Non-electric (thermal, pressure, etc.)

2.3.2 Incoming Signal

- current
- voltage
- power
- frequency
- temperature
- pressure
- speed
- others

2.3.3 Function

- over current
- directional over current
- distance
- overvoltage
- differential
- reverse power
- others

2.4 Operation of Protective Relay

Electromechanical protective relays operate by either magnetic attraction, or magnetic induction.

"Armature"-type relays have a pivoted lever supported on a hinge or knife-edge pivot, which carries a moving contact. These relays may work on either alternating or direct current, but for alternating current, a shading coil on the pole is used to maintain contact force throughout the alternating current cycle. Because the air gap between the fixed coil and the moving armature becomes much smaller when the relay has operated, the current required to maintain the relay closed is much smaller than the current to first operate it. The "returning ratio" or "differential" is the measure of how much the current must be reduced to reset the relay.

A variant application of the attraction principle is the plunger-type or solenoid operator. A reed relay is another example of the attraction principle.

"Moving coil" meters use a loop of wire turns in a stationary magnet, similar to a galvanometer but with a contact lever instead of a pointer. These can be made with very high sensitivity. Another type of moving coil suspends the coil from two conductive ligaments, allowing very long travel of the coil.

"Induction" disk meters work by inducing currents in a disk that is free to rotate; the rotary motion of the disk operates a contact. Induction relays require alternating current; if two or more coils are used, they must be at the same frequency otherwise no net operating force is produced.

Protective relays can also be classified by the type of measurement they make. A protective relay may respond to the magnitude of a quantity such as voltage or current. Induction types of relay can respond to the product of two quantities in two field coils, which could for example represent the power in a circuit. Although an electromechanical relay calculating the ratio of two quantities is not practical, the same effect can be obtained by a balance between two operating coils, which can be arranged to effectively give the same result.

Several operating coils can be used to provide "bias" to the relay, allowing the sensitivity of response in one circuit to be controlled by another. Various combinations of "operate torque" and "restraint torque" can be produced in the relay.

By use of a permanent magnet in the magnetic circuit, a relay can be made to respond differently to current in one direction than in another. Such polarized relays are used on direct-current circuits to detect, for example, reverse current into a generator. These relays can be made bitable, maintaining a contact closed with no coil current and requiring reverse current to reset. For AC circuits, the principle is extended with a polarizing winding connected to a reference voltage source.

Light weight contacts make for sensitive relays that operate quickly, but small contacts can't carry or break heavy currents. Often auxiliary telephone-type armature relays are triggered by the measuring relay.

In a large installation of electromechanical relays, it would be difficult to determine which device originated the signal that tripped the circuit. This information is useful to operating personnel to determine the likely cause of the fault and to prevent its re-occurrence. Relays may be fitted with a "target" or "flag" unit, which is released when the relay operates, to display a distinctive colored signal when the relay has tripped.

Chapter: 3

Faults & Solution

3.1 Different type of faults Occurred in Power plant

Electrical power system has a dynamic and complex behavior. Different types of faults can interrupt the health operation of the power system. Some of the major Electrical faults are phase faults include phase to phase faults and phase to ground faults and three phase faults. Other Electrical faults are of no major significance but still are considered, Open circuit faults occurs due to the parting of the over headline or failure operation of the circuit breaker, Interterm fault occurs due to the overvoltage or insulation breakdown, Electrical Faults results in the overloads is due to the passing the current through the conductor which is above the permissible value and faults due to real power deficit occurs due to mismatch in the power generated and consumed and results in the frequency deviation and collapse of grid.

3.1.1 Phase Faults:

Electrical Phase faults are characterized as:

- Phase to Ground Fault
- Phase to Phase Fault
- Phase - Phase to Ground Fault
- Three Phase Fault

Phase to Ground Fault:

In this type of Electrical fault all the three sequence components (positive, negative and zero sequence components) are present and are equal to each other. In case of isolated neutral connection to the generator, there will be no return path for the current. So for such fault, fault current is zero.

Phase to Phase fault:

These are unsymmetrical faults as these faults give rise to unsymmetrical currents (Current differ in magnitude and phase in the three phases of power system).In case of Phase to Phase fault positive and negative sequence component of current are present, they are equal in magnitude but opposition in phase. Zero sequence components are absent.

Phase - Phase to Ground Fault:

These faults are of unsymmetrical nature. In this type of faults negative and zero sequence faults are in opposition with positive sequence components.

Three Phase Fault:

This type of faults are called symmetrical fault. This type of faults occurs very rarely but more severe compared to other faults. In this faults negative and zero sequence component currents are absent and positive sequence currents are present.

To summarize:

- positive sequence currents are present in all types of faults
- Negative Sequence currents are present in all unsymmetrical faults
- Zero sequence currents are present when the neutral of the system is grounded and the fault also involves the ground, and magnitude of the neutral currents is equal to $3I_0$

3.1.2 Open Circuit Faults:

Open circuit faults occur either by overhead line parting or pole of the circuit breaker not fully closing. These results in load imbalance on generators and motors lead to negative phase sequence components in the stator current. This negative phase sequence component currents rotate at twice the supply frequency in the opposite direction in relation to the rotor and causes additional eddy current losses, results in temperature raise in the rotor.

3.1.3 Interterm faults:

Interterm faults occur in machines i.e., Transformers, Motors and Generators. An Interterm fault occurs due to the insulation breakdown between the turns of the same phase or between the parallel windings belonging to the same phase of the machine. The cause of the interterm fault is usually an overvoltage or mechanical damage of the insulation.

Interterm Faults are more severe on large alternators (generators), High voltage motors and power transformers. Interterm fault is most often experienced in rotating machines where multiple windings are present in the same groove. For large generators generally single winding rod per groove is designed in such cases interterm fault can occur only in the winding head region.

Interterm Fault can occur at both stator and rotor for rotating machines like generators and motors.

When an interterm fault occurs on stator of a rotating machine there is a high probability that such fault can lead in to the ground fault.

When Interterm faults occur on the rotor winding following symptoms are observed:

- When such fault occur high excitation current is required and this is compensated by the voltage regulator.

- Machine runs less smoothly, because of the asymmetry of the excitation curve
- magnetization of the shaft due to asymmetrical flux
- Bearing damage due to current flowing in the bearings

Interterm faults on power transformers can be occurred due to the overvoltage's accompanying ground faults or deterioration of the insulation due to chemical influence of the transformer oil.

Interterm fault current depends on the number of the terms shorted and fault currents will be several times higher than the rated current of the windings and thus damages the windings.

3.1.4 Overload:

Faults due to overload will occur due to exceeding the maximum permissible load current through the windings, cables, or transmission lines or due to reduction in the cooling offered to the windings.

Electrical conductor is designed in such a manner that the conductor allows permissible amount of current without getting over heated. In this manner the current carrying rating of the conductor is decided. When the current passed through the conductor is above permissible level, no immediate damage occurs but over a period of time conductor insulation will be damaged due to the excess heat generated.

In large generators and power transformers of large MW ratings, the heat generated is enormous, so forced fooling is provided in such cases. For large generators hydrogen cooling is provided and for large transformers forced cooling is provided. This part is nicely presented in Transformer Cooling Methods. When these cooling methods fail then the damage to the equipment is certainly fast compared to the other case.

3.2 Overcome procedure of faults occurred in power plant

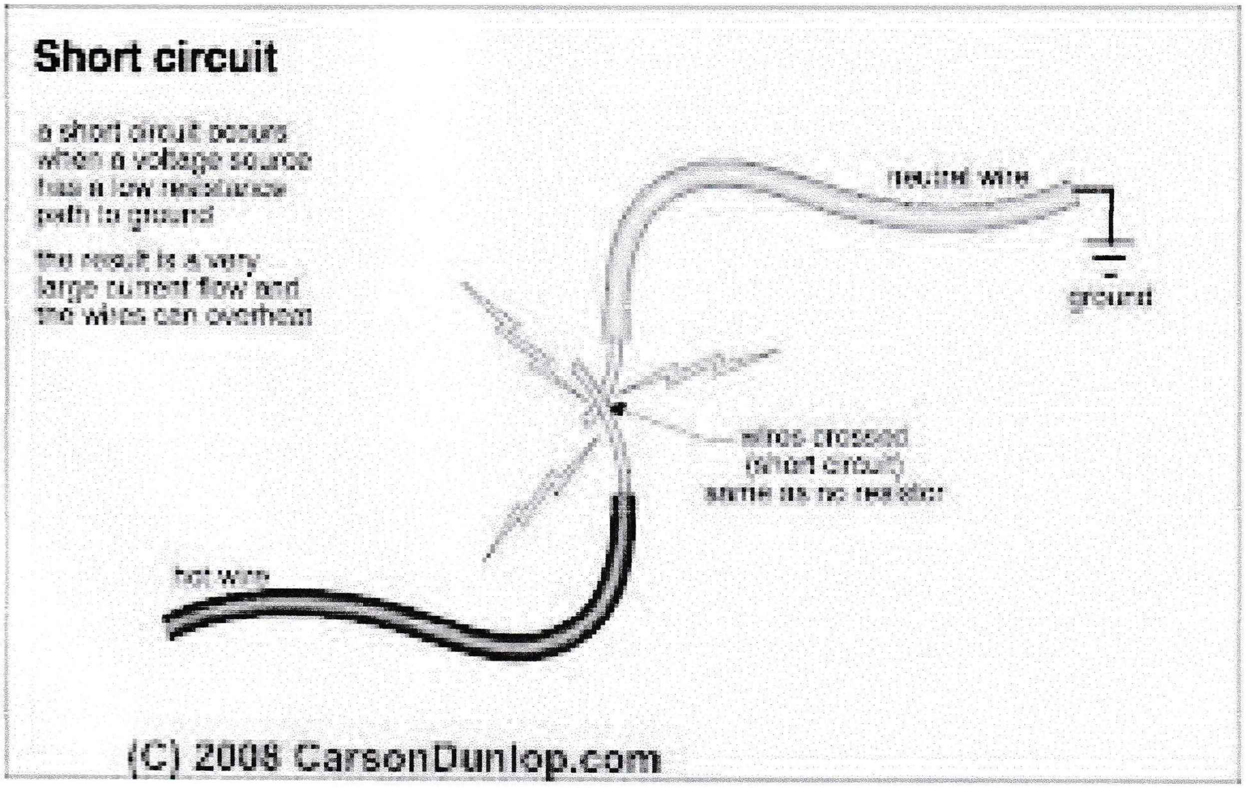
3.2.1 Faults in Components

Stator Core End Plates Hot Spots:

Improper design or construction can lead to irreparable damage. Dreaded problems such as core end plate burning are amongst those consequences. When generators operate in leading power factor mode the air gap flux density increases excessively. This leads to a significant increase in the fringing flux density in the end winding region, inducing eddy currents in the core end plates, resulting in local overheating and burning. Once the core burning starts, it forms a so called 'hotspot" and gradually grows. The heat generated from the hot spots can cause damage to the surrounding lamination insulation, encouraging further burning.

Back-of-Core Burning Fault

It occurs in the back of the core between the stator core laminations and their support key bars. The burning is a result of electrical arcing from the current transfer between core laminations and the key bars through poor electrical



contacts.

Fig: 3.1 Short Circuit Current

Problems:

In normal operation, the generator is filled with hydrogen gas at 300kPa pressure and the stator coolant system is charged with dematerialized water at 200kPa. The purpose for the differential in the pressure is to prevent water leakage into the stator insulation system. if any small leaks occur in the stator coolant system due to faults such as cracks in conductors or leak gaskets, hydrogen gas escapes into the stator coolant water and is collected in a gas catchment chamber. An alarm is triggered and hydrogen gas is vented safely into the atmosphere. Usually, hydrogen leaks are small and the loss of hydrogen pressure is insignificant. If the cracks were allowed to grow, excessive hydrogen gas in stator coolant water could seriously reduce cooling capacity of the sub-conductors leading to local overheating, eventually, deformation of the sub conductors and severe damage to the stator conductor.

End Winding Looseness Problem

It is found that in most cases where cracked sub conductors are found there is evidence of excessive inter-conductor movement within the end-winding and relative to their support structures. As the conductors vibrate in service, they rub against one another and their support system. Excessive amount of insulation fretting dust is a cause for alarm as it is indicative of a significant loss of insulation material; a sign of dangerous degradation of conductor insulation system, thus increased risk of discharge and electrical faults.

3.2.2 Advisable Practices Remedial Solutions

After identifying the problem area it is important to take corrective actions. Actions taken often help to make good inspection & condition monitoring techniques. Some of them are shown below.

(a) Remedy for Stator Lamination Relaxation Core laminations must remain tightly pressed together for the entire life of the generator to avoid local overheating related problems. To paint each major section of the generator such as core front, core back, core end plate and end windings, with a different special type of paint. In the case of local heating occurring in a particular area, the paint will release specific chemicals that can be detected by routine gas analysis. This technique is used at a number of power stations because it provides an additional means of monitoring generator stator for this particular parameter: local overheating. There are Limitations to this technique though. Many areas in a generator stator are not accessible and cannot be painted. Faults cannot be detected if they occur outside of the painted areas.

(b) Dealing with Stator Core End Plate Faults As the hot spots result from excessive eddy currents generated on the core end plates, their propagation can be stopped by minimizing the fringing axial magnetic flux perpendicular to the core end plate or replacing the core endplate with one made of non-magnetic material, together with significantly increased cooling at the core ends.

(c) Dealing with Back-of-Core Burning Fault the two main factors responsible for back-of-core burning faults are: the movements of stator core laminations relative to the core key bars and the magnetic leakage flux in the axial direction and in the back of the core. A remedial solution has been adopted in a number of large generators to control the damage due to the back-of-core burning fault. Copper shorting straps are installed to electrically connect the adjacent key bars formed a squirrel cage arrangement in the back of the core. This provides a low impedance path for the stray currents to flow between the key bars and therefore by-passing the intermittent high impedance interface between the key bars and core laminations. This modification has been successful and has been proven to stop the further propagation of back force burning faults.

(d) In most cases, if spare conductors are available, conductor replacement is a preferred option. In contrast conductors in each phase group of a water box design stator are different due to the physical arrangement of the cast resin water boxes making spare holding expensive. There are several options to repair cracked sub-conductors such as blocking cracked sub conductors; and removing cracks by shortening the conductor. Where both of the above options are not suitable, a third option can be adopted: the complete conductor is replaced with a spare.

3.2.3 Inspection and Conditioning Monitoring techniques

After taking corrective actions, it is important to implement good inspection & condition monitoring techniques to prevent further damage & to improve continuity of operation. Different techniques are described with their merits & Demerits.

(a) Experience shows that visual inspection is one of the most practical and useful techniques in inspection and condition monitoring. In addition to being simple and cost effective type of form, Visual inspection covers a wide range of examination criteria and, in many cases; it invariably discovers new defects that have not been detected by sophisticated equipment. However, visual inspection should only be utilized as a preliminary examination technique and not replace other analytical inspections and tests. In general, visual inspection is carried out at the beginning and the end of generator overhaul or outages. Table 1 show the complete test & maintenance schedule with their need & time period. A quality assurance system is prepared to guide the inspector who performs the visual inspection and to record all findings. It also gives the details of different inspections that are taken care of with its need of preventive maintenance.

(b) Stator core lamination tightness test It is very important to check the tightness of stator core laminations as part of generator routine inspection program. The inspection procedure is relatively simple but effective to detect such faults. The tightness is checked by inserting a thin tapered toughened knife blade between the core laminations by hand. Such a tool is commonly called a core knife. The thickness and the taper angle of the core knife are precisely machined to predetermined dimensions so that a consistent assessment criterion is applied throughout the inspection. The depth of insertion of the knife blade is noted during the test. The test heavily relies on the experience of the test technician. Although somewhat subjective, it is usually quite obvious to an experienced inspector when loose laminations are found. The test is still the simplest and the most practical way to determine the tightness of core laminations with the least intrusion and minimal risk of damage to stator core lamination insulation.

3.2.4 Start new aid projects with power technology

Current status and Challenges

The estimation and evaluation of nuclear power seems to be restricted only to commercial nuclear power plant. But nuclear power technologies can be utilized in various fields. Nuclear energy is used in several non-electric applications, including seawater desalination and district heating. It has the potential for expanded use in desalination, in extracting non-conventional oil, in co-generation with coal and in hydrogen production for transport (Majumda2002). To compensate sustainable loss from waste, safety and cost increasing, Nuclear power need to expand their role in saving lives, growing crops and providing jobs in the developing world (IAEA, 2008)

Improvement direction

- Respond aggressively to pressing global crises in food security, health and the availability of drinking water through the use of nuclear techniques

- Develop small-medium size nuclear power technology and project

Feasible actions (By international organization such as IAEA, UN, World Bank)

- Raising fund through international organization's share of the expenses for the projects related with nuclear technology to help countries in need
- Facilitating small-medium size nuclear power reactor R&D and seawater desalination project in water and electricity deficient country with international aid.

Expectations

Nuclear reactor can help billions of poor people need energy and other life-saving and job-creating technologies

Flagship project can prove the superiority of nuclear power by supply water and energy

3.2.5 Correction Procedure of different types of faults

Inspection & Maintenance Schedule

(a) Stator core end plate hot spot inspection the core end plate burning fault is difficult to be detected with a reasonable degree of confidence while the generator is in service. To date, visual inspection is still the best known method to detect and monitor this problem. Unfortunately, it requires an outage of the generator with the end covers removed. For a hydrogen-cooled generator, this task can take a few days and some considerable cost. In some rare fortunate cases, the fault is detected by the thermocouples embedded immediately behind the core end plate within a few centimeters of fault location. Unfortunately, there is a practical limit of the number of thermocouples that can be embedded in the core and they cannot be relied on for detection of localized overheating faults such as core end plate burning. A core end plate hot spot that occurs more than a few centimeters away from a thermocouple may not be detectable. The main objective of this paper has been to outline the experience on some of the significant operational faults in large synchronous generators. The paper gives the suggestions on future directions in terms of fault prevention and long term asset maintenance strategies of large synchronous generators. The electricity market plays a major role in driving the operational regime of large synchronous generators. Inevitably, it demands from the participating generators capacity, flexibility and availability. The arduous operating conditions coupled with machine ageing and, in some cases, unsuitable designs have been responsible for a range of operational faults in large synchronous generators. A well balanced combination of visual inspection, online condition monitoring and offline routine examination is by far the best health check for large synchronous generators.

3.2.6 More frank with hidden costs of power plant

Current status and Challenges

Nuclear power cannot be free from suspicious eyes on hidden costs. To make matters worse, nuclear power has not only one but several hidden costs. However nuclear power may need not be shy on these problems because every energy source has its own hidden costs (Geoff Keith, 2012). All hidden cost of energy sources is variable according to method of calculations and assumptions. The main reason for nuclear power to lose its credibility from people may be from not hidden cost but deviousness (OECD, 2010). If nuclear industry does its best to clear nuclear power's hidden costs, most people would not stand by nuclear side any more.

Improvement direction

- Active participation of evaluation nuclear power

- Keep a modest attitude to criticism from anti-nuclear power group

Feasible actions

- Carry out regular calculation about environmental costs with at least neutral figures; If possible, IAEA or OECD can have an important role in this process.
- Analysis the result of subsidies from government, compare with other sources and make a disclosure of results by IAEA or OECD
- Make a plan about how to reduce hidden or real costs through R&D, cooperation with countries(prepare for subsidy reform in future, this works done by each nation)

Chapter: 4

Power Plants

4.1 BACKGROUND

Electricity Generation Company of Bangladesh (EGCB) Limited have installed a 412 MW Combined Cycle Power Station and associated Substation at Haripur, financing by the Japan International Cooperation Agency (JICA) of Japan.The Plant comprises of One Mitsubishi MHI Model M701F4 Gas Turbine Generator of 279.42 MW rating (Site conditions). One Doosan Heat Recovery Steam Generator with HP steam flow of 309.76 tons/hrs at 131.2 bars and 568^0 C, 50.88 t/h (IP system) and 43.12 t/h (LP steam) at GT base load. One Fuji Steam Turbine Generator of 149.2 MW rating. Balance of Plant (BOP) and other auxiliary equipment/systems required for the operation of the Plant. The Electricity Generation Company of Bangladesh (EGCB) Limited have engaged Earnest & Young LLP as Management Consultants for establishing management procedures and train/assist EGCB personnel in efficient operation and maintenance of the Plant as a

Strategic Business Unit (SBU). This document outlines the performance parameters of the Plant, their relevance and the procedures for monitoring the same on regular basis. Key Point Indicators (KPI) are defined for continuous monitoring and evaluation.

ABBREVIATIONS

ASME	American Society of Mechanical Engineers
BOP	Balance of Plant
CT	Cooling Tower
DCS	Distributed Control System
DM	De Mineralized (water)
EGCB	Electricity Generating Company of Bangladesh
GCV	Gross Calorific Value
GSA	Gas Supply Agreement
GTG	Gas Turbine Generator
GT	Generator Transformer
Ho_{met}	Net Heat Rate
HRSG	Heat Recovery Steam Generator
KPI	Key Performance Index (Indices)
LCV	Lower Calorific Value
LDC	Load Dispatch Center
PLF	Plant Load Factor
PPA	Power Purchase Agreement
STG	Steam turbine Generator

4.1.1 FINANCIAL MODEL

Financial Model of an enterprise is created with a view to ensure the overall profitability and sustainability of an enterprise. The primary role of ensuring profitability is assigned to the Finance Department which controls and monitors the finances of the enterprise. The key performance indices for the Finance Department are the following:

Current Ratio

This is a ratio of Current Assets to Current Liabilities. This ratio is an important indicator of financial health of the organization. In the case of EGCB, the target value for this KPI is 2:1 for the year 2014-15. This KPI is monitored on monthly and yearly basis.

Quick Ratio

Quick Ratio is a modification of the Current Ratio to the extent that Current Inventory value is deducted from the current assets and then the same is divided by current liabilities. Target for this KPI, for EGCB is kept as 1:1 for the year 2014-15. Inventory in this case is the spares available in Stores.

Debt Service Ratio

This ratio is derived by dividing the total debts by the debts cleared. This is an indicator of the liquidity of the enterprise. For EGCB, the target value for 2014-15 is 1.5 against which a value of 1.02 has been achieved during July 2014. This KPI is monitored monthly and yearly.

Finance Department, along with Efficiency Group of Operations, is also responsible for calculating the cost of generation. Cost of generation, Taka/unit, consists of the following components:

Capital cost

O&M Cost

Fuel Cost

This cost of generation is compared with the sale price (Taka/unit) derived on the basis of Power Purchase Agreement (PPA). Profitability of the power plant is ensured when the cost of generation is less than sale price.

4.1.2 OPERATIONAL PERFORMANCE of Haripur power plantas a KPI

Optimum operational performance of the Power Plant is the main factor for the financial health of the enterprise. Through optimum performance of the plant, O&M cost and fuel cost can be optimized (reduced) leading to higher margins between cost price and sale price of power produced. The most important performance parameters to be continuously monitored in the operating station are:

heat rate at base/operating load.

Heat rate is the amount of heat energy in kJ or kcal required to produce a unit of electrical energy in kw/hr. Therefore it bears a direct relationship with the quantum of fuel consumed by the plant. The higher the heat rate, the higher is fuel consumption resulting in higher cost of generation. This single parameter therefore is most important for the optimum performance and profitability of the Plant and needs to be closely monitored. This can be done by

- Continuous monitoring from Plant Performance Module available in DCS.

- Calculation from gas consumption and power produce/delivered (once per day and once per month)

Continuous monitoring through DCS should be on per shift basis. For comparison/analysis of data, it is necessary to make temperature, pressure, humidity and power factor corrections by using OEM supplied correction curves.

Heat Rates are defined as

Gross Heat Rate when the electrical energy is measured at Generator Terminals and

Net Heat rate when the electrical energy is measured at generator transformer outlet terminals.

Net Heat rate takes into consideration the Auxiliary Consumption and therefore is representative of the export (saleable) energy. This heat rate should therefore be considered for evaluation of Plant performance.

Depending upon the type of fuel calorific value (GCV or LCV) used in heat rate calculations; Heat Rate is further classified as Heat rate (GCV) or HR (LCV). Since Lower Calorific Value (LCV) represents the utilizable heat, HR (LCV) should normally be considered in performance evaluation.

The Efficiency Engineer should continuously monitor the trend of Heat Rate - is it increasing or decreasing? When an increasing trend is observed, Plant Systems should be checked/analyzed to find out the cause of this trend and steps taken to maintain Heat rate within prescribed limits.

It is also recommended to conduct **periodic performance tests, at least once in a quarter** in order to establish validity of test data obtained from DCS. The procedure to be followed for these tests should be the same as the Test

Procedure for Guarantee Performance, except that installed measuring instruments may be used instead of temporary external instruments. However, calibration data and their validity must be ensured before such tests.

Daily average and **Monthly** average **net Heat Rates** are recommended as Plant KPI. Monthly average HR is essential for billing purposes. These heat rates are calculated as:

$$\text{Daily average HR} = \frac{Gas\ consumed\ in\ 24\ hrs.xGas\ LCV}{Export\ Energy\ in\ kwhr}$$

Gas consumption for 24 hersis measured from the gas custody meter installed at inlet of gas conditioning station of the plant.

Gas LCV is averaged from the chromatograph (installed at metering station) readings.

Export energy is taken from the tariff meters installed at HT side of generator transformers.

Guarantee Heat Rate is the Heat Rate guaranteed by the Original Equipment Manufacturer (OEM). For Haripur CCP, the guarantee heat rate values along with PPA admitted values are as below:

Parameter	**Combined Cycle Mode**			**Open Cycle Mode**
	100%	75%	50%	100% GT
Output, MW	412.797	318.011*	220.550*	272.877
Heat Rate LHV, kJ/KWH	6,435	6,609	7,228	9,735
PPA (HHV)	7220	7415	8110	10923

The difference in the PPA specified heat rate and the actually achieved operational heat rate contributes to the profit margin. That is why operational average heat rate is an important performance indicator. When the monthly average heat rate is lower than the PPA specified heat rate, the plant performance is good as it contributes to profit. The larger the difference, the higher is the profit.

Heat rate is inversely proportional to plant efficiency. Plant efficiency is given by the following formula:

Plant Efficiency = 3600/Heat Rate when Heat Rate is expressed in kJ/kwh units.

4.1.3 AUXILIARY POWER CONSUMPTION of the Haripur power plant

The in house consumption of electric power for running power plant auxiliaries is termed as Auxiliary Consumption. The main auxiliaries in a combined cycle power plant are:

- Cooling Water Pumps
- River Water Pumps
- Boiler Feed Pumps
- Cooling Tower Fans
- Condensate extraction pumps

Auxiliary Power Consumption is an important parameter to monitor as it contributes to the net exportable energy from the Plant. This also affects the net heat rate - the higher the auxiliary power consumption, the higher will be the net heat rate. The auxiliary power consumption therefore needs to be the minimum possible and any increase should be carefully investigated. Auxiliary consumption of a combined cycle plant should not exceed 3 to 3.5% of generated power. Auxiliary Power Consumption can be measured by one of the following methods:

1. Difference in power produced at generator terminals and at HT side of generator transformer. This will indicate all power used internally by the plant including HVAC, station lighting loads etc. which are generally not included in auxiliary power consumption of the plant during performance guarantee test. However, this is a realistic figure as it pertains to net exportable power.
2. Adding the power consumed by individual auxiliaries essential for running of the plant. This method is laborious and there is a danger of omitting some of the auxiliaries that may be operating during the performance evaluation. This method is therefore not used in day to day estimation of Auxiliary Power Consumption, but used during Plant Performance guarantee test.

4.1.4 Different terms of power plant

PLANT LOAD FACTOR (PLF)

Plant Load Factor (PLF) is an indicator of Plant loading. It is the ratio, in percent, of the power generated at generator terminals (sum of power generated at all operating generators in case of multi generator the plant.

This is an important KPI as is indicative of plant utilization. PLF depends upon grid conditions and is dictated by the Load Dispatch Center (LDC)/PPA. Plant KPI like HR, auxiliary power consumption and emission levels change with change in PLF and are optimum at PLF of 90% and above. PLF should therefore be maintained at the highest possible level. In the case of combined cycle plants, plant performance deteriorates rapidly at PLF of 70% and below.

In the case of Haripur, this factor is termed as Plant Factor and is a ratio of the plant actual load to the dependable Capacity which is declared as 409.247 MW. This is targeted at 50% for the year 2014-15.

DM WATER CONSUMPTION

DM water consumption is an important indicator of plant health and therefore needs to be closely monitored. Higher DM consumption indicates higher steam leakages as well as abnormal (higher) boiler blow down. DM water consumption should be kept below 1% of steam flow. A KPI is therefore proposed for this also.

EMISSIONS

r plant) to the declared capacity Emission levels though do not contribute to plant economics but are important for meeting statutory requirements. These should therefore be constantly monitored to ensure that the values of SO_x,NO_xetic are maintained within the stipulated values. A KPI is therefore proposed on this account. Guarantee emission levels are as below:

Constituent	**Guarantee Limit**			
	100%	**45%**	**Start Up**	**Shut Down**
NO_x (ppmv)	25	25	60	60
SO_x (ppmv)	0	0	0	0
CO (ppmv)	190	190	4000	4000
Particulates (mg/Nm^3)	50	50	50	50

Above values have been met during the performance guarantee tests of the plant.

4.1.5 GAS TURBINE AND ASSOCIATED EQUIPMENT of Haripur Power Plant

Gas turbine, being the heart of the Plant, need to be maintained in a perfect condition in line with OEM guidelines. Of particular importance are the following areas:

- Periodic inspection and replacement of Air Intake Filters. This result in keeping air inlet pressure drop low leading to sustained high efficiency.
- Online/Offline Compressor cleaning as per requirements. Prevents deterioration of compressor efficiency.
- Operation of Gas Turbine at highest possible PLF through persuasion of LDC Staff.
- Scheduled Maintenance as per OEM Recommendations. Leads to higher availability and efficiency.

4.2 HRSG AND ASSOCIATED EQUIPMENT

Properoperation and maintenance of HRSG ensures generation of steam as per design parameters, which in turn ensure design output from the steam turbine. The biggest cause of inadequate performance of HRSG is the heat loss at entry and improper heat transfer. To prevent this, following need to be done.

- Periodic inspection of gas exhaust duct expansion joints and repairs/replacement as required. This will prevent leakages leading to lower losses
- Periodic inspection of diverter damper and checking of any gas leaks. Ensure damper operation especially sealing system as per guaranteed performance.
- Periodic inspection and repair of exhaust duct insulation.
- Check and prevent excessive steam leakage from valves and other equipment. This prevents higher DM consumption.
- Maintain boiler feed water and steam chemistry as per OEM recommendations. This will lead to high quality steam and maintain CBD/IBD levels. High quality steam prevents salt deposits in turbine blades which lead to sustained turbine efficiency.
- Monitor and control CBD and IBD.

4.3 COOLING TOWERS AND ASSOCIATED EQUIPMENT

Circulating water from the condenser is cooled in Cooling Towers. In the event of in-efficient operation of Cooling Towers, temperature of water at outlet of cooling towers will rise leading to high CW temperature at inlet to condenser and higher condenser pressure. This, in turn, will reduce steam turbine output leading to higher heat rate. Though the biggest contributor to Cooling Tower poor performance is high humidity, following actions need to be taken to ensure that performance does not further deteriorate due to other causes that can be controlled. Following needs to be prevented:

- Damaged or blocked sprayers
- Damaged packing
- Excessive mud deposition in the pond
- Ponds trash screens partially choked or damaged
- Excessive blow down.

Keep the tower clean and the water distribution uniform to obtain continued maximum cooling capacity. Do not allow excessive deposits of scale or algae to build up on the fill or eliminators. Keep the distribution nozzles free of debris to assure correct distribution and cooling of water. Water should be kept clean by treatment, screening, or filtering to avoid the possibility of fill clogging and loss of thermal performance.

The capacity of cooling tower to cool water to a given cold water temperature varies with the wet-bulb temperature. The higher the difference between dry and wet bulb temperatures, the higher will be the cooling.

Air is caused to move through the tower by operation of the electric motor-driven fans. At full speed, these fans are designed to move the amount of air required to accomplish the design thermal performance. Proper utilizations of these fans provide the operator a means by which to adjust the level of thermal performance to suit the requirements of the load. Fans are provided with variable pitch mechanism. Fans should be adjusted to OEM recommended pitch in order to meet the cooling requirements as well as optimize fan power consumption.

OEM recommended maintenance schedule must be followed for continued trouble free performance of Cooling Towers (refer to document MC-CW-G-61-N012-00).

4.3.1 CONDENSER

Condenser vacuum can be a major cause of lower plant efficiency (higher heat rate). Poor condenser vacuum may be due to one or several of following:

- Higher CW inlet temperature (due to poor performance of Cooling Towers)
- Lower than design CW flow (poor performance of CW Pumps, condenser tube sheet blockage). This is inferred from higher than design CW outlet temperature
- *Air ingress due to condenser leakage or poor performance of vacuum pumps*
- Deteriorated heat transfer due to condenser tube fouling, blockage or larger number of tube plugging.

Condenser for Haripur CCP steam turbine is designed to provide a back pressure of 0.114 bars at a cooling water temperature of 38.7^0 C and a flow of 32,450 m^3 /hr. *Maximum temperature rise of cooling water is 16^0 C.*

4.3.2 Condenser – Poor Performance Causes & Remedies

Cause	**Remedy**
High CW Inlet Temp.	Check Cooling Tower performance
Low CW Flow (High CW outlet temp.)	Fully open CW inlet/outlet valves Start standby CW pump Open Water Box-check and remove debris blocking tube sheet.
Poor heat transfer (Higher TTD)	OperateTube Cleaning System
Airingress (poor vacuum)	air leakage through condenser body/turbine condenser joint to be investigated and rectified. Check condenser shell by air leakage test and rectify leakage. Check performance of vacuum pump and start standby vacuum pump if performance is found inadequate.