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COMBINED CYCLE GAS POWER GENERATING STATION: POWER SYSTEMS AND PROTECTION

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ABSTRACT

This work gains technical learning from the operation of a combined cycle gas power project aimed at achieving high energy efficiency from naphtha. This formed a bridge between theoretical and practical knowledge. In the olden days, the Power Stations were constructed to run either on coal or with water (that is getting collected in the catchment area), which are called thermal or hydropower stations, respectively. The power stations are operated on gas either in open cycle or in combined cycle mode. As the operation in open cycle is costly, the power producers prefer running the gas power station only in combined cycle mode rather than in simple cycle mode because of the cost consideration. These power stations have become much more popular because of the many considerations described in this paper, along with process optimization in leaning industry towards fuel efficiency and integration of renewable energy systems. Working principle of protection schemes and operations become further explored topics under this research paper. All types of major power system protection schemes, as applied in this paper, entail future scopes.

Keywords: Power Plant, Combined Cycle Power Plant, Gas Fuel, Generation, Energy.

I. INTRODUCTION

Combine cycle power plant integrates 2 power conversion cycles. Brayton cycle (GT) and Rankine cycle(ST) with the principle objective of increasing overall plant efficiency. The overall combine cycle efficiency comes to 45% **[1]**. Achieving the Efficiencies of homes in power usage in **[2] [3] [4]** combines with combined cycle power generation aimed at reducing the lost power from process flows. On contrary, electricity prices influences the power usage **[5]**. As you are all aware in general the Gas Turbines can produce about 55 **-** 58% extra energy thru' the Steam Turbine from out of the steam generated in Heat Recovery Steam Generators (HRSGs) with the heat exchange that is taking place between flue gases and the water inside the HRSGs **[6]**. These power stations have become much more popular because of the following considerations:

1. Starting of the units and bringing them on to the bar is easier/faster when compared to the thermal units.
2. When used on gas these units are quite cost effective.
3. When the right equipment is selected, these are good work horses, which can be continued in service after synchronization without much trouble. There are minimum numbers of controls when compared with the thermal unit of the same capacity.
4. The efficiency of the combined cycle unit is about 48% when compared to about 35% of thermal units. Of-course the efficiency of Trent Engines is about 56%.
5. The personnel required to operate combined cycle plant of the same capacity is much less than that of a thermal plant.
6. These are short gestation projects which take less time for installation & commissioning. The Gas units are fully automatic and of single button operating units and they can be started & loaded sequentially.

Operation of Combined Cycle Power Plant

The working of the gas turbine starts with the starting of the turn gear and then the cranking motor which rotates the shaft of the compressor which is coupled through a torque converter. The compressor compresses the inlet atmospheric air to 10 bars which is then fed to the combustion chamber for combustion of fuel (can be naphtha, gas, or high speed diesel) which produces flue gas [7]. Now the gas turbine which performs the major function of using the flue gas energy and movement of generator rotor and winding. The rotation of turbine rotor at synchronous speed rpm gives rated frequency in Hz A.C. The power output of generator is at rated MW at rated voltage in KV. This power can be transmitted to several kilometers so now it is being step up to 220 KV by a step up transformer which is then given to the switch yard and then to the power grid.

The gas plant can run in both forms either in **open cycle or combined cycle**. In open cycle the exhaust of the gases is passed to the atmosphere through a by pass chimney where as in combined cycle the exhaust gases are used to heat up water to steam to run steam turbine.

When working in combined cycle the exhaust gases (540^{0} C) are passed through boiler. The boiler has a typical arrangement of different layers of economizer, evaporator, superheater and preheater with two drums HP and LP [8] [9].

The water from feed water tank is pumped to HP as well as LP economizer which increases the temperature of the water. This water then reaches HP and LP drum respectively. From these drums, pumps are used to pump the water to evaporator which converts water to steam. This steam is passed through superheater, which further increases temperature of steam. The HP steam from both the boilers is then fed to HP turbine. At the exhaust of HP turbine both HP and LP steam are mixed and then feed to LP turbine. The generator connected to the turbine produces power at rated MW which is again supplied to step up transformer. Water is passed through condenser which converts steam to water and now this cooling water goes to cooling tower. Thus, produced water is collected in hotwell which is further pumped into the feed water tank through a preheater which increases the temperature of water.

Gas Turbine

The gas turbine is a common form of heat engine working with a series of processes consisting of compression of air taken from atmosphere, increase of working medium temperature by constant pressure ignition of fuel in combustion chamber, expansion of SI and IC engines in working medium and combustion but it is like steam turbine in its aspect of the steady flow of the working medium. Gas Turbine has an operating efficiency of 31% and 49% in open cycle and combined cycle mode respectively when natural gas is used as fuel [7]. Today gas turbine unit sizes with output above 250 MW at ISO conditions are being designed and developed. Modern renewable energy systems from solar FPV in [10] increases the need for developing power system improvement planned in capital projects [11] like combined cycle power plants.

Compressor

The axial-flow compressor section consists of the compressor rotor and the casing. Included within the compressor casing are inlet guide vanes, the 17 stages of rotor and stator blading, and the exit guide vanes. In the compressor, air is confined to the space between the rotor and stator blading where it is compressed in stages by a series of alternate rotating (rotor) and stationary (stator) airfoil-shaped blades.

The rotor blades supply the force needed to compress the air in each stage and the stator blades guide the air so that it enters in the following rotor stage at the proper angle. The compressed air exits through the compressor-discharge casing to the combustion chambers. Air is extracted from the compressor for turbine bearing cooling sealing, and for pulsation control during start-up (to avoid surging). Since minimum clearance between rotor and stator provides best performance in a compressor, parts have to be assembled very accurately [9].

Compressor is used to increase the pressure of air and that pressurized air is injected into the combustion chamber, so that proper combustion of fuel takes place. For starting the compressor rotor cranking motor is used and when the speed reaches to 60% of the operating speed the cranking motor is cut off and now the compressor rotor rotates with the rotation of turbine rotor as both of them are coupled together. This is known as self -sustaining stage assisting the energy efficiency stages [12].

The amount of air entering the compressor depends on the working condition of the gas turbine i.e. either it is running on full load or on no load or is in start up or shutdown sequence. Inlet Guide Vane (IGV) is used to control the amount of inlet air to the compressor. It is operated by servo valve mechanism by which its blade moves from 34 to 84 degrees which controls the amount of inlet air according to the load.

Optimization

The comparison of the efficiencies of the combined cycle is compared with the simple cycle and shown in the Figure 1 [13].

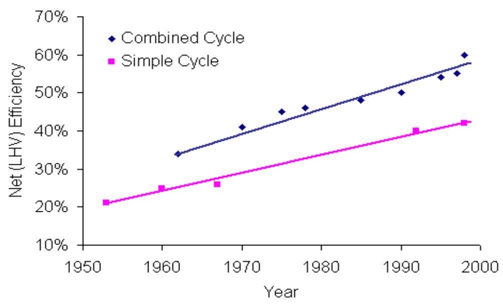

Figure 1. Combined Cycle Vs Simple Cycle [14]

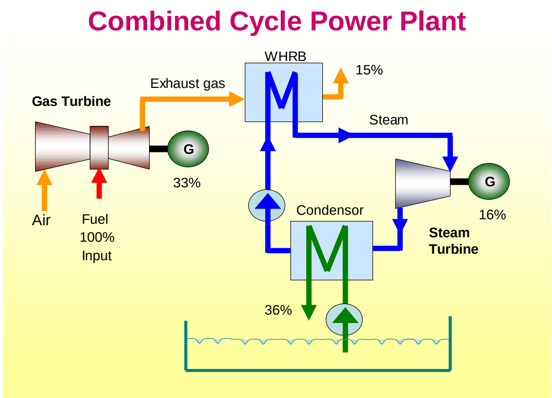

Figure 2. Combined Cycle Power Plant Schematic Diagram [6]

Electrical Protections

The various types of power system protection in power generation and transmission in reflected in the Figure 3.

- Generator and transformer protections
- 6.6 kV Protections
– Station transformer protections
– Motor protections
– Transformer protections
- 220 kV Protections
– Line protections
– Busbar protection
– Breaker failure protection

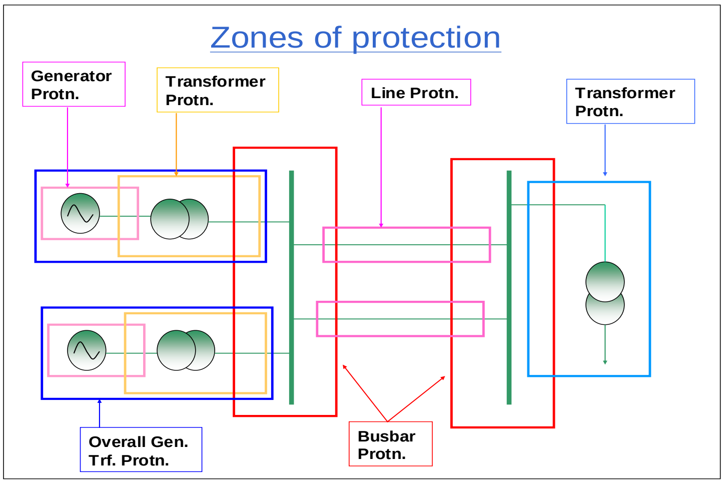

Figure 3. Zones of Protection

Generator Protections

- Generator Differential Protection

- Generator Stator earth fault protection 100%
- Generator Stator earth fault protection 95%
- Generator rotor earth fault protection
- Overall differential protection
- Transformer restricted earth fault protection
- Generator Transformer Over fluxing relay
- Generator reverse power relay
- Backup impedance relay
- Generator Loss of excitation protection
- Generator Negative phase sequence current protection
- Stator Over voltage protection
- Stator Under voltage protection
- Under frequency relay
- Voltage balance relay
- Too long field flashing protection.
- Protection against back energization
- Protection against DC failure
- The diode matrix

Medium Voltage Substation Protections

- Station transformer protections
  – Three phase Overcurrent protection.
  – Earthfault protection.
  – Restricted earth fault protection.
- Motor protection
  – IDMT over current protection
  – Earthfault protection
- Transformer protection
  – IDMT over current protection
  – Earthfault protection

High Voltage Line protections

Line protections

- Main I Distance protection (21-1)
- Main II Distance protection (21-2)
- Breaker failure relay.
- Trip circuit supervision relay
- Trip coil supervision relay.
- Fault locator
- Disturbance recorder

High Voltage Transformer protections

- Transformer Differential protection.(87)
- Three phase overcurrent protection. (51)
- Earth fault relay (Phase current balance)
- Breaker failure relay.
- Bucholz relay
- Winding temperature relay
- Oil temperature relay
- Pressure relief device

High Voltage Busbar protection

- Differential protection
- To protect against fault on main bus bars and the transfer bus.
- Bus I zone differential relay

- Bus II zone differential relay
- Check zone relay

Breaker failure protection

- To protect against circuit breaker malfunctions
- Gives command to trip the 220 kV busbar on which the equipment is connected when:
– Trip command is existing from any relay and
– Current has not died out even after 200 ms.

Application of Protection Scheme

The figure 4 shows the busbar schemes. Any bay can be connected to either bus1 or bus2 by isolator 1 & 2. There is a breaker in each bay which is hydraulically operated. Isolator 4 allows the transmission of the power of any bay through transfer bus in case there is fault in that bay. Only one bay can be switched to transfer bus at a time. Transfer bay is used to charge the transfer bus from main bus for providing the alternate path of power flow as described above. Bus coupler is used to couple the two buses for maintaining both at constant voltage otherwise unnecessary circulating current will be developed which will cause overheating. Additional of modern loads from electric vehicles [15] [16] [17]causes several concerns of demand response problems as indicated in [18].

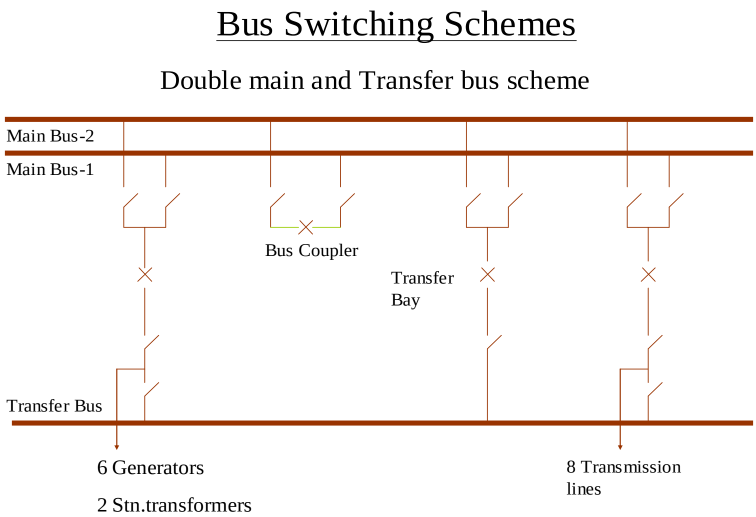

Figure 4. Practical Scheme

II. CONCLUSION

The basic operation of a combined cycle power plant resulted in higher efficiency of operation. The breaker protection scheme developed in the practical application presented an approach to solving the power system protection problems in the real world. Transfer bus is normally dead and is used in case any one of the bay is having fault. It provides an alternate path for the flow of power in case of fault. It can be used only if one has to work on the isolator and breaker of that bay. Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction, and then “dumped” into the environment even though it could still be reused for some useful and economic purpose. The essential quality of heat is not the amount but rather its “value”. This waste heat recovery is future scope of work. As the operation in open cycle is costly, the power producers prefer running the gas power station only in combined cycle mode rather than in simple cycle mode because of the cost consideration.

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