International Journal of Scientific Research & Engineering Trends
Volume 4, Issue 5, Sep-Oct-2018, ISSN (Online): 2395-566X

Enhancement of Thermal Plant Efficiency by Using Double Pipe Heat Exchanger

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***Abstract** – The heat exchanger section of a thermal power plant uses water as a coolant, which is incapable of extracting the low grade heat input in the heat exchanger section. This results in loss of a major chunk of heat energy from the thermal power plant. However, with the use of a proper coolant in the heat exchanger section, it is possible to utilize the heat available in the heat exchanger. This can be done by introducing a secondary cycle for energy generation along with the conventional primary cycle. Isobutane, with its appropriate physical properties, proves to be a good coolant in the secondary cycle for energy extraction from the low grade heat available in the heat exchanger section. The efficiency of a conventional thermal power plant can be improved from 80% to around 87 – 87.65% by incorporating this change. Although, the paper details the improvement of efficiency in a thermal power plant, same methodology can be used in any steam operated power plant, such as in nuclear power plants, in geothermal power plants, or in solar thermal electric power plants. The improvement in efficiency leads to lesser burden on non-renewable resources, such as coal and nuclear fuel, and also lowers the pollution effects on the environment. Proper practical implementation of the proposed model has the potential to revolutionize the energy generation paradigm of the world.*

Keywords: **Rankin cycle, conventional thermal power plant, low grade heat energy, secondary turbine generator system, natural refrigerants.**

I. FUNCTIONALITY OF A THERMAL POWER PLANT

Thermal power plant (TPP) is a power plant in which the prime mover is steam driven. Water is heated, turns into steam and spins a steam turbine which drives an electrical generator. After it passes through the turbine, the steam is condensed in a condenser. The greatest variation in the design of TPPs is due to the different fuel sources. Some prefer to use the term energy center because such facilities convert forms of heat energy into electrical energy [3-5]. In TPPs, mechanical power is produced by a heat engine which transforms thermal energy, often from combustion of a fuel, into rotational energy. Most TPPs produce steam, and these are sometimes called steam power plants. TPPs are classified by the type of fuel and the type of prime mover installed (Figure 1).

The electric efficiency of a conventional TPP, considered as saleable energy produced at the plant busbars compared with the heating value of the fuel consumed, is typically 33 to 48% efficient, limited as all heat engines are by the laws of thermodynamics. The rest of the energy must leave the plant in the form of heat. 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.

This overheated steam drags the HP rotor (high pressure) of the turbine in rotation and relaxes to the exit of the HP body of the turbine, so it comes back again in the furnace to be until 540°

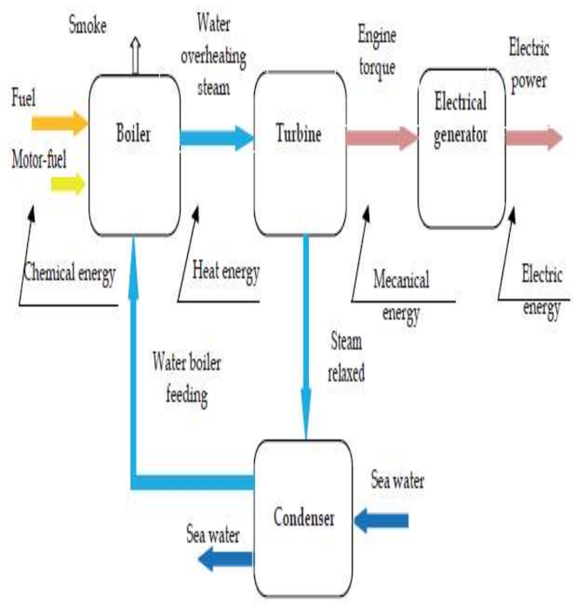

Figure 1. Functionality of a TPP.

After, it will be sent back to the MP body (intermediate pressure) then to the BP body (low pressure) of the turbine. During these steps, the calorific energy is transformed in available mechanical energy on the turbine. Thus, this mechanical energy will be transmitted to the alternator, being a generator of alternating current, in the goal to produce the electric energy. After the condensation, water will be transmitted thanks to pumps of extraction in the station of BP to be warmed progressively before being sent back to the furnace through the intermediaryof the food pumps.

This warms progressive of water has for goal to increase the output of the furnace and to avoidall thermal constraints on its partitions. And this station of water is composed of a certainnumber of intersections that is nourished in steam of the three bodies of the turbine. Finally,the cycle reproduces indefinitely since steam and water circulate in a closed circuit.During this cycle water recovers the calorific energy in the boiler that it restores at the time ofits detente in the turbine as a mechanical energy to the rotor of the turbine. The rotor of theturbine being harnessed to the rotor excited of the alternator, the mechanical energy of theturbine is transformed then in electric energy in the alternator.Turbine constitutes an evolution exploiting principal's advantages of turbo machines: masspower and elevated volume power; improved efficiency by the multiplication of détente floors [6-8].

II.PROCESS DESCRIPTION OF A COAL-FIRED POWER PLANT

A coal-fired power plant burns coal to produce electricity. In a typical coal-fired plant, there are pulverizes to mill the coal to a fine powder for burning in a combustion chamber of the boiler. The heat produced from the burning of the coal generates steam at high temperature and pressure. The high-pressure steam from the boiler impinges on a number of sets of blades in the turbine. This produces mechanical shaft rotation resulting in electricity generation in the alternator based of Faraday's principle of electromagnetic induction. The exhaust steam from the turbine is then condensed and pumped back into the boiler to repeat the cycle. This description is very basic, and in practice, the cycle is much more complex and incorporates many refinements.

A typical coal plant schematic is presented in Figure 1. It shows that the turbine of the power plant has three stages: high-pressure, intermediate-pressure and low-pressure stages. The exhaust steam from the high-pressure turbine is reheated in the boiler and fed to the inter-mediate-pressure turbine. This increases the temperature of the steam fed to the intermediate pressureturbine and increases the power output of the subsequent stages of the turbine. Steam from different stages of the turbine is extracted and used for boiler feed water heating. This is regenerative feed water heating, typically known as regeneration. The improvement of the thermal performance of the power generation cycle with reheat and regeneration is a tradeoff between work output and heat addition [8] and it can be evaluated through the efficiency of the power generation cycle.

III. PROCESS MODELING AND SIMULATION

Mathematical models are effective tools for analyzing systems or processes. They can be used to develop a new system or to evaluate the performance of an existing one. Mathematical modelling is widely applied to the solution of engineering problems. Modelling usually describes a system using a set of variables and equations and sets up relationships among the variables. Mathematical models are found to be very useful in solving problems related to process energy efficiency and can be utilized for both static and dynamic systems. MATLAB [1],
A process modelling software package, has been found to be very effective for analyzing plantsfor efficiency improvement. It has been used in Australia by a number of process industries,consulting companies and universities as a tool for simulating plant. Therefore, MATLAB has been employed in this study for modelling and simulating the said coal-fired power plant.

IV.APPLICATION OF SYSTEM ANALYSIS FOR THERMAL POWER PLANT HEAT RATE IMPROVEMENT

In order to improve the performance of a thermal power plant (TPP), it is necessarily to adopt performance monitoring and heat rate improvement. To improve efficiency, the engineer must knew the heat input, the mass of fuel, the fuel analysis and the kW rating generation in order to determine the actual heat rate. After the actual heat rate calculated and understood, losses must be identified and understood. Good communication and teamwork between the engineer and staff within the TPP is essential to success [1-2].

In fact, the heat rate is defined in units of Btu /kWh (KJ / kWh) and is simply the amount of heat input into a system divided by the amount of power generated by of a system [1].The calculation of the heat rate enable to inform us on the state of the TPP and help the engineer to take out the reasons of the degradation of the TPP heat rate in order to reach the better one recorded at the time of acceptance test when the equipment was new and the TPP was operated at optimum. Therefore, this TPP heat rate value is realistic and attainable for it has been achieved before [1-2]. The global efficiency of a TPP is tributary of a certain number of factors and mainly of the furnace efficiency. Otherwise, there is place to also notice that with regards to the turbine and the alternator that are facilities of big importance in the constitution of a TPP, the degradation of their respective efficiencies hardly takes place long-term of a manner appreciable and this by reason of the ageing of some of their organs as: stationary and mobile aubages usury; increase of the internal flights; usury of alternator insulations, etc.

V. MAIN OBJECTIVES AND GOAL OF PROJECT

The objective of this paper is to analyze the different losses of a TPP therefore to implant solutions in order to act in time and to improve its efficiency. Appropriate performance parameters can enable the performance engineer to either immediately correct performance or estimate when it would be cost effective to make corrections. In fact, the performance parameters measure how well a TPP produces electricity.

These actions or decisions are [1]:

- **Improve TPP operation;**
- **Predictive maintenance;**
- **Comparison of actual to expected performance;**
- **Improved efficiency of TPP;**
- **Reduce uncertainty in actual costs for better MW sales.**

VI.THERMAL POWER PLANT EFFICIENCY

Thermal efficiency (□)

In thermodynamics, the thermal efficiency (□) is a dimensionless performance measure of a device that uses thermal energy, such as an internal combustion engine, a steam turbine or a steam engine, a boiler, a furnace, or a refrigerator for example. In general, energy conversion efficiency is the ratio between the useful output of a device and the input, in energy terms. For thermal efficiency, the input, Qin, to the device is heat, or the heat-content of a fuel that is consumed. The desired output is mechanical work, Wout, or heat, Qout, or possibly both. Because the input heat normally has a real financial cost, a memorable, generic definition of thermal efficiency is [1]

$$\eta_{th} \equiv \frac{\text{output}}{\text{input}}.$$

From the first law of thermodynamics, the energy output cannot exceed the input, so

$$0 \leq \eta_{th} \leq 1$$

When expressed as a percentage, the thermal efficiency must be between 0% and 100%. Due to inefficiencies such as friction, heat loss, and other factors, thermal engines' efficiencies are typically much less than 100%. For example, a typical gasoline automobile engine operates at around 25% efficiency, and a large coal-fueled electrical generating plant peaks at about 46%. The largest diesel engine in the world peaks at 51.7%. In a combined cycle plant, thermal efficiencies are approaching 60%. [2] Such a real-world value may be used as a figure of merit for the device. For engines where a fuel is burned there are two types of thermal efficiency: indicated thermal efficiency and brake thermal efficiency. [3] This efficiency is only appropriate when comparing similar types or similar devices. For other systems the specifics of the calculations of efficiency vary but the non-dimensional input is still the same

Efficiency = Output energy / input energy

Rankine cycle: steam power plants The Rankine cycle is the cycle used in steam turbine power plants. The overwhelming majority of the world's electric power is produced with this cycle. Since the cycle's working fluid, water, changes from liquid to vapor and back during the cycle, their efficiencies depend on the thermodynamic properties of water. The thermal efficiency of modern steam turbine plants with reheat cycles can reach 47%, and in combined cycle plants, in which a steam turbine is powered by exhaust heat from a gas turbine, it can approach 60%.[4]

Brayton cycle: gas turbines and jet engines The Brayton cycle is the cycle used in gas turbines and jet engines. It consists of a compressor that increases pressure of the incoming air, then fuel is continuously added to the flow and burned, and the hot exhaust gasses are expanded in a turbine. The efficiency depends largely on the ratio of the pressure inside the combustion chamber p2 to the pressure outside p1

$$\eta_{th} = 1 - \left(\frac{p_2}{p_1}\right)^{\frac{1-\gamma}{\gamma}}$$

Efficiency of thermal power plant is quite low. It mainly depends upon following three major factors:

- **Pressure**
- **Temperature of the steam entering into the turbine**
- **Pressure in the condenser**
- **Heat exchanger heat flow**

A huge amount of heat is lost in the condenser due to various stages of the plant. Heat energy cannot be converted into mechanical energy without temperature difference and according to the thermodynamics lawwe know, greater the temperature difference, greater the heat energy is converted into mechanical energy. So, **thermal efficiency** increases with the increase in temperature and the pressure of steam are entering the turbine. The thermal efficiency is also effectively increased by decreasing the pressure in the condenser but if the pressure of the condenser is too low (nearly 0.04kg/cm2), the plant will run at low efficiency according to the thermodynamics law .

VII.PROPOSED DOUBLE PIPE HEAT EXCHANGER

A double pipe heat exchanger, in its simplest form is just one pipe inside another larger pipe. One fluid flows through the inside pipe and the other flows through the annulus between the two pipes. The wall of the inner pipe is the heat transfer surface. The pipes are usually doubled back multiple times as shown in the diagram at the left, in order to make the overall unit more compact. The term 'hairpin heat exchanger' is also used for a heat exchanger of the configuration in the diagram. A hairpin heat exchanger may have only one inside pipe, or it may have multiple inside tubes. The principal disadvantage to the use of double pipe exchangers lies in the small amount of heat-transfer surface contained in a single hairpin. The time and expense required for dismantling and periodically cleaning are prohibitive compared with other types of equipment. However, the double pipe exchanger is of greatest use where the total required heat-transfer surface is small, 100 to 200 ft^2 or less. [3]

Types of Double Pipe Heat Exchangers:-

1. Counter flow
2. Parallel Flow Heat Exchanger

1. Counter flow

The main advantage of a hairpin or double pipe heat exchanger is that it can be operated in a true counter flow pattern, to get More Efficiency, in the mean Time, it will give the highest overall heat transfer coefficient for the double pipe heat exchanger design.

2. Parallel Flow

Parallel Flow double pipe heat exchangers are focused to handle high pressures and temperatures applications. Also we can Achieve High Log mean Temperature using this.

3. Genetic Algorithm

Genetic Algorithm (GA) works on the theory of Darwin□s theory of evolution and the survival-of-the fittest [1]. Genetic algorithms guide the search through the solution space by using natural selection and genetic operators, such as crossover, mutation and the selection. Professor John Holland of the University of Michigan envisaged the concept of these algorithms in the mid-sixties.

GA encodes the decision variables or input parameters of the problem intosolution strings of a finite length. While traditional optimization techniques work directly with the decision variables or input parameters, genetic algorithms usually work with the coding. Genetic algorithms start to search from a population of encoded solutions instead of from a single point in the solution space. The initial population of individuals is created at random. Genetic algorithms use genetic operators to create Global optimum solutions based on the solutions in the current population. The most popular genetic operators are (1) selection, (2) crossover and (3) mutation. The newly generated individuals replace the old population, and the evolution process proceeds until certain termination criteria are satisfied.

Section

The selection procedure implements the natural selection or the survival-of-the fittest principle and selects good individuals out of the current population for generating the next population according to the assigned fitness. The existing selection operators can be broadly classified into two classes: (1) proportionate schemes, such as roulette-wheel selection and stochastic universal selection and (2) ordinal schemes, such as tournament selection and truncation selection. Ordinal schemes have grown more and more popular over the recent years, and one of the most popular ordinal selection operators is tournament selection. After selection, crossover and mutation recombine and alter parts of the individuals to generate new solutions.

Crossover

Crossover, also called the recombination operator, exchanges parts of solutions from two or more individuals, called parents, and combines these parts to generate new individuals, called children, with a crossover probability. There are a lot of ways to implement a recombination operator. The well-known crossover operators include one-point crossover. When using one-point crossover, only one crossover point is chosen at random, for example let there be two parent string A1 and A2 as:

A1= 1 1 1 1| 1 1
A2 = 0 0 0 0|0 0

Then, one-point crossover recombines A1 and A2 and yields two off springs A-1 and A-2as:

A-1 =1 1 1 1|1 1
A-2 =0 0 0 0|1 1

Mutation

Mutation usually alters some pieces of individuals to form perturbed solutions. In contrast to crossover, which operates on two or more individuals, mutation operates on a single individual. One of the most popular mutation operators is the bitwise mutation, in which each bit in a binary string is complemented with a mutation probability.

Step-by-Step Implementation of GA

Step 1: Initialize GA parameters which are necessary for the algorithm. These parameters include population size which indicates the number of individuals, number of generations necessary for the termination criterion, crossover probability, mutation probability, number of design variables and respective ranges for the design

International Journal of Scientific Research & Engineering Trends
Volume 4, Issue 5, Sep-Oct-2018, ISSN (Online): 2395-566X

variables. If binary version of GA is used then string length is also required as the algorithm parameter.

Step 2: Generate random population equal to the population size specified. Each population member contains the value of all the design variables. This value of design variable is randomly generated in between the design variable range specified. In GA, population means the group of individuals which represents the set of solutions.

Step 3: Obtain the values of the objective function for all the population members. The value of the objective function so obtained indicates the fitness of the individuals. If the problem is a constrained optimization problem then a specific approach such as static penalty, dynamic penalty and adaptive penalty is used to convert the constrained optimization problem into the unconstrained optimization problem.

Step 4: This step is for the selection procedure to form a mating pool which consists of the population made up of best individuals. The commonly used selection schemes are roulette-wheel selection, tournament selection, stochastic selection, etc. The simplest and the commonly used selection scheme is the roulette-wheel selection, where an individual is selected for the mating pool with the probability proportional to its fitness value. The individual (solution) having better fitness value will have more number of copies in the mating pool and so the chances of mating increases for the more fit individuals than the less fit ones. This step justifies the procedure for the survival of the fittest.

Step 5: This step is for the crossover where two individuals, known as parents, are selected randomly from the mating pool to generate two new solutions known as off-springs. The individuals from the population can go for the crossover step depending upon the crossover probability. If the crossover probability is more, then more individuals get chance to go for the crossover procedure. The simplest crossover operator is the single point crossover in which a crossover site is determined randomly from where the exchange of bits takes place.
Step 6: After crossover, mutation step is performed on the individuals of population depending on the mutation probability. The mutation probability is generally kept low so that it does not make the algorithm unstable.

Step 7: Best obtained results are saved using elitism. All elite members are not modified using crossover and mutation operators but can be replaced if better solutions are obtained in any iteration.

Step 8: Repeat the steps (from step 3) until the specified number of generations or termination criterion is reached.

VIII.RESULT AND SIMULATION

1.Autocad 3d View Heat Exchager Design:

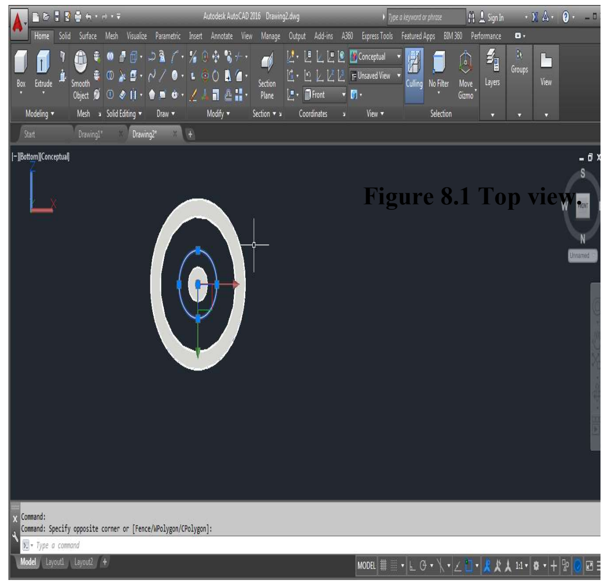

Figure 8.1 Top view

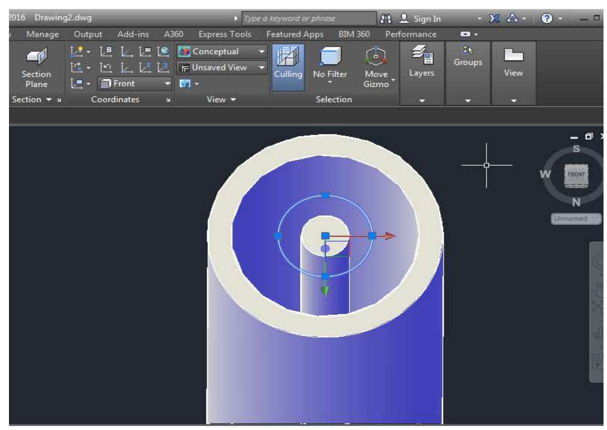

Figure 8.2 Right view.

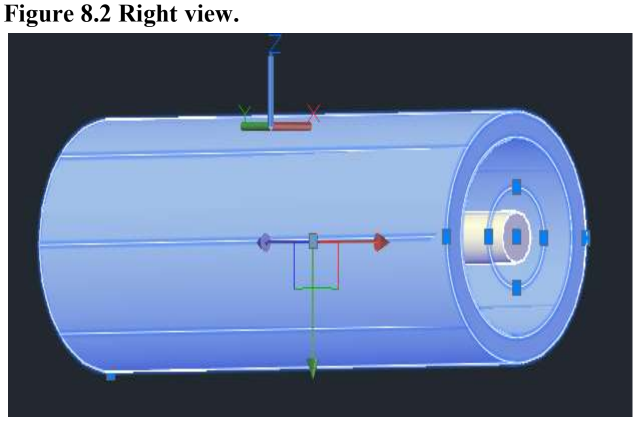

Figure 8.3 Side view.

2. MATLAB Simulink modelling in Thermal power plant.

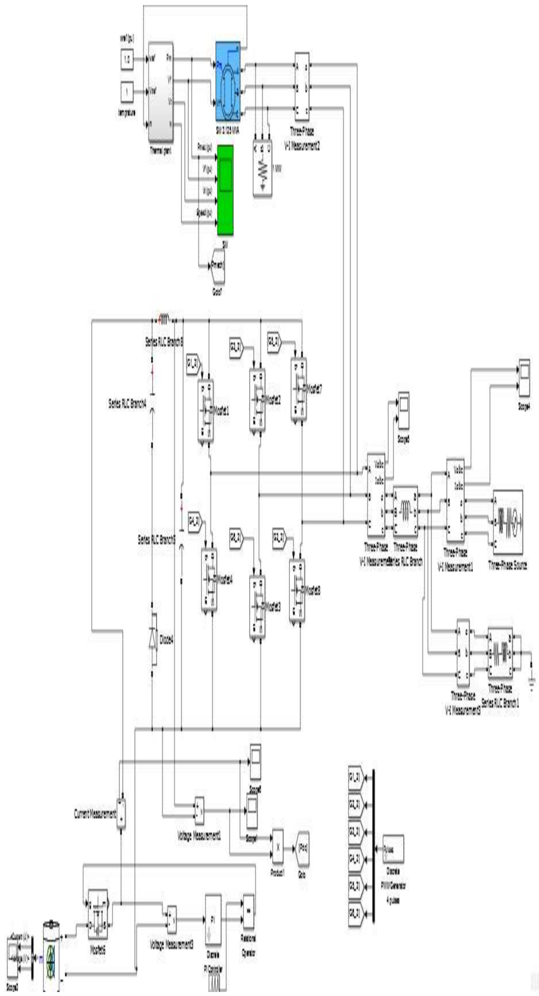

Figure 8.4Simulink modelling in Thermal power.

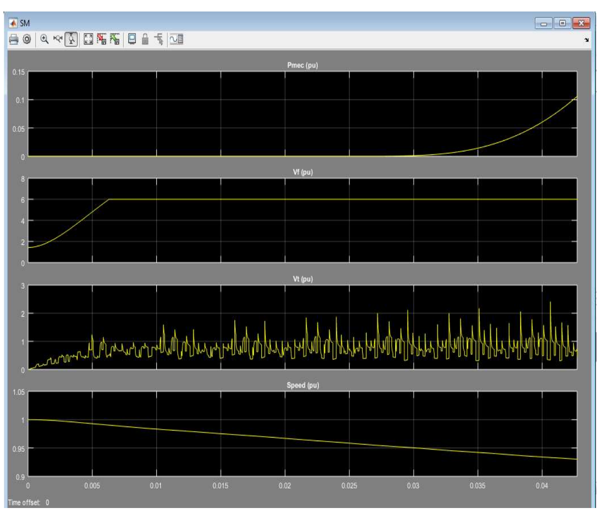

Figure 8.5Output of Simulink modelling in Thermal power.

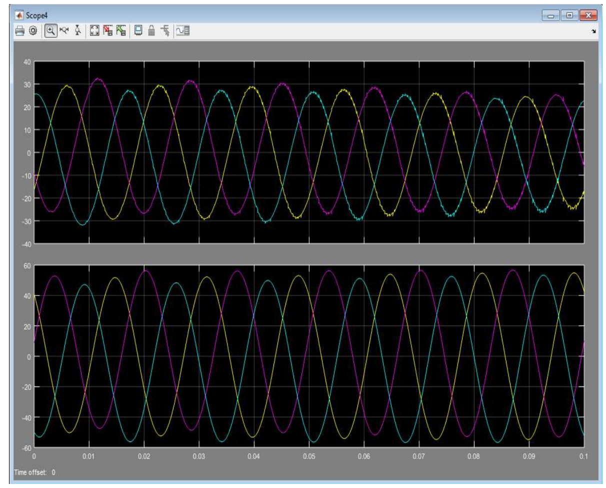

Figure 8.6Three phase Output of Simulink modelling in Thermal power Plant.

IX. CONCLUSIONS

In this thesis, the dynamic operation of a thermal plant generator-battery plant in off grid power supply is simulated in Power Factory. The primary and secondary control of active power is considered to compensate the active power fluctuations, which result from the variations of the load and PV field power. Four control strategies are proposed to represent different contribution to the primary and secondary control between the battery energy storage system (BESS) and the diesel generators.

1- Control strategy (1): the primary control is provided by the diesel generators and the BESS in parallel, and the secondary control is provided only by the BESS.

2- Control strategy (2): the primary and secondary control is provided by the diesel generators and the BESS in parallel.

3- Control strategy (3): the primary and secondary control is provided mainly by the BESS.

4- Control strategy (4): the primary control is provided mainly by the BESS, while the secondary control is provided by the diesel generators and the BESS in parallel.

The control strategies are compared according to four criterions; the frequency deviations, fuel consumption, the expected lifetime of the batteries and the performance of the diesel generators.

The results show that each control strategy leads to a different level of variations in the output power of the diesel generators and the BESS. Control strategy (3) leads to more constant output power close to the nominal value of the diesel generators, whereas control strategy (2) leads to a higher level of variations in the output power of the diesel generators, while control strategy (4) and (1) lead to the second and third higher levels of the variations in the loading of the diesel generators respectively.

• In general, when the primary and secondary control covers the power fluctuations from the BESS, the output power of the diesel generators becomes more constant and close to the nominal value.

• The frequency deviations are lower when the BESS mainly provides the primary and secondary control of active power to cover the power fluctuations.

• The fuel consumption is lower when the output power of the diesel generators is constant and close to the nominal value, which means that the power fluctuations are compensated by the BESS. As a result, CO_2 emission is lower in this control strategy. In this case, the fuel consumption is 3.5% lower than in the case, in which power fluctuations are covered by the BESS and the diesel generators in parallel.

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