2nd Conference for Engineering Sciences and Technology -
CEST2 29-31 October 2019 - Sabratha –Libya

A Drum Boiler Turbine Unit Performance Improvement Using PID Control

Mahmoud Aiyad Ghwila[1*], Ahmed Farhat Zrigan[2] , Ali A Mehna[3]

[1] magawila@gmil.com, [2] Ahmedzrigan@gmil.com, [3]alimehna@gmail.com

[1] Department of electrical and Electronics Engineering, University of Zawia , Libya
[2]Department of Electrical and Electronic technology, Higher Institute of Science and Technology Tripoli, Libya
[3] Dean of faculty of engineering - Sabratha

ABSTRACT

Fossil fueled power plant (FFPP) refers to a group of power generation devices that convert the chemical energy stored in the fossil fuel such as coal, gas, oil into thermal energy, mechanical energy and finally electrical energy. The main part in thermal power plant is boiler, that plays main role in steam generation. A boiler Turbine system provides high-pressure steam to drive the turbine in thermal electric power generation.

Steam generation systems are a crucial part of most power plants. Therefore, boiler control is an important problem for power plants that are frequently changing load or subject to sudden load disturbances, which are common in current market driven electricity industry. In such circumstances it is required to keep the boiler operating well for large changes in the operating conditions, therefor, the major control objective of a boiler-turbine system is to keep the output of mechanical energy in balance with the electrical load demand while maintaining the internal variables such as drum steam pressure, temperature and drum water level within the desired ranges. One way to achieve this is to incorporate more process knowledge into the control system (Aström and Bell, 2000) In this paper general theory of boiler turbine unit (BTU) is presented, including the steam cycle, the control system of the plant. The equations that are used for the modelling of the plant are also explained.

Keywords: Boiler turbine unit; MIMO PID controller; LQG; MIGO Methods; control,MATLB\SIMUKLINK.

1. Introduction

A power system is designed to provide the electrical power to consumers with high quality characteristics.

Connect or disconnection loads for any reason causes random fluctuations around these patterns. In addition, electrical energy cannot be stored in large quantities of electric energy and must be produced according to consumer's needs. As a result, the power system does not work in stability, it always tries to match power generation with the load.

The operation of boiler turbine unit (BTU) is as follows: - First, the electrical power needed by the load, at the given frequency, determines the counteracting electromagnetic torque that is to be equalized by the actuating mechanical torque produced by the steam turbine as power at a given speed. So that, frequency is used to determine the generation-load balance, and indicates that, if the frequency is higher than nominal value, it means that the generation is greater than the load, and if the frequency is less than nominal value, it means that the generation is less than the load, and when the frequency at the nominal value, this means that the generation matches the load. Second, the prime mover torque is a function of the steam flow energy into the turbine, which in turn is a function of the steam pressure and temperature from here, the steam pressure before the throttle valves is used to determine the boiler-turbine energy balance. The boiler will produce more steam the turbine required if the throttle pressure increases, if the throttle pressure decreases then the boiler is producing less steam than required. When the throttle pressure is constant the oiler is matching the steam needed by the turbine. Third, the rate of steam produced is determined by the rate of burning fuel.

Adjusting the firing rate is done by adjusting both the flow of fuel and air to maintain safe and complete combustion.

Generally, any operator in a FFPU must provide two operating requirements: Generating the required electrical power, and at the same time, he must maintain the energy balance within the unit. They satisfy these requirements by BTU board instrumentation, the adequate regulation of generated power, main steam pressure, and drum water level. To do this, they adjust the main steam flow, fuel and air flows, and feed water flow.

The theory of boiler turbine unit is simple. Whereas consists of alternator runs by steam turbine. The steam is produced in high pressure and obtained by burning the fuels such as oil or gas or coal in boiler, the boiler also termed as "Steam Generator". This steam also supper heated in a super heater. This supper heated steam enters into the turbine and rotates the turbine blades. The turbine is coupled with alternator that its rotor will rotate with the rotation of turbine blades. The steam pressure after imparting energy to the turbine suddenly falls and passes out of the turbine blades into the condenser. In the condenser, sea water is circulated by pump which condenses the low pressure wet steam and becomes water [2]. This condensed water is heated by heaters and used again. The most variation in the design of power plants is due to the different fuel sources. A steam power plant continuously convert the energy stored in fossil fuels into shaft work and finally into electricity. [2] Practically, a steam power plant cycle was suggested by Rankine cycle. In the Rankin cycle, the water will be as a working substance. In this cycle, water is pumped from a low pressure to a high pressure by a feed water pump. [3] Then the water temperature increases at constant pressure and it is converted to superheated steam. This steam is expanded in a turbine to generate work. The output of the turbine is then cooled in a condenser to the liquid state and fed to the feed water pump. [4] In actual boiler turbine units, various modifications are incorporated to improve the thermal efficiency, hereas, input temperature and the heat of working fluid are increased by superheating the main steam and reheating, and regenerative heating of feed water. This shown in figure 1 and the changing in the thermodynamic cycle is shown in figure 2.[5]

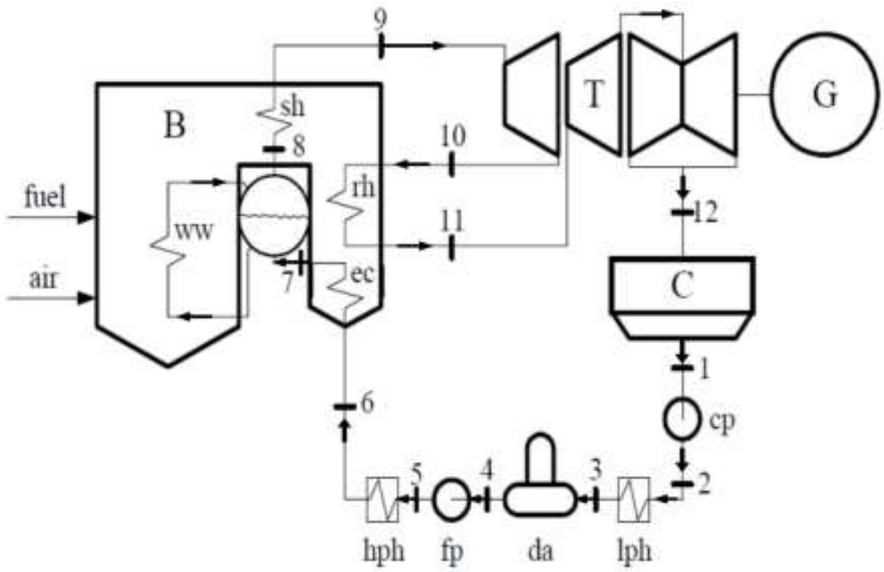

Figure 1. fossil fuel power unit

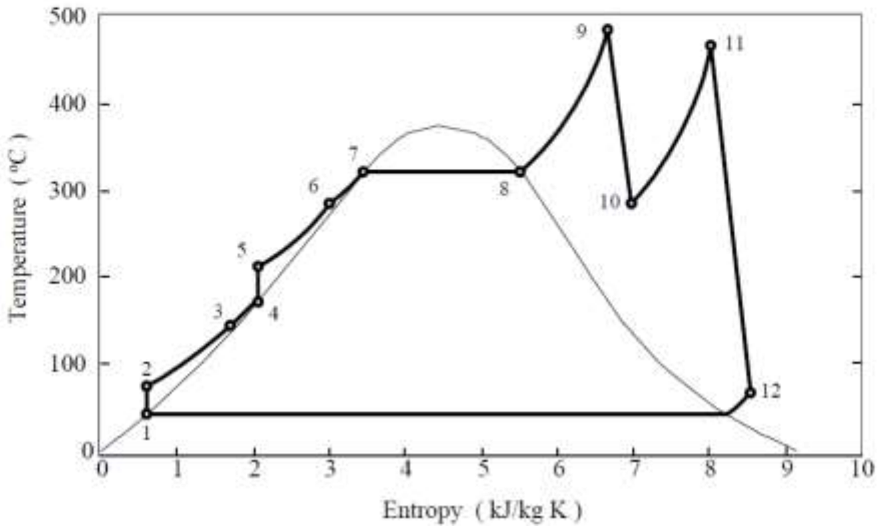

Figure 2. Temperature-entropy diagram of Rankine cycle

Feed water regenerative heating is carried out by kinds of heaters: economizer, deaerator, and closed heaters. [3] Feed water path (points 1 through 7), and superheating takes place in primary and secondary super heaters at constant pressure and increasing in temperature from state 8 to state 9. The isentropic expansion takes place through the high pressure turbine from point 9 to 10, and before entering the low pressure turbine section, the steam is taken again to a superheated vapor condition (point 11). Finally, another isentropic expansion takes place through the low pressure turbine section (point 12). [4] Boiler turbine unit in power plants also are designed to produce heat energy for a wide range of industrial purposes - electricity generation, chemical processes, heating. The process is continuous and large scale. Industrial purposes of district heating, or desalination of water, in addition to generating electrical power. Generally, fossil fueled Boiler turbine units produce a huge of CO2 emissions to the atmosphere, and efforts to reduce these are different and well-known. [6]

1.1 Important Notices.

The steam-water side and combustion side are very different processes. The interaction between them must be carefully regulated. Bad regulation will have serious consequences. The water level will drop in the drum if the evaporation rate is greater than the feed water flow rate. Likewise, the drum level will continue to rise if the feed water flow rate is greater than the evaporation rate, and then overflow will occur into the super heater tubes, causing huge thermal shock. [22] Temperature of super-heated steam must be maintained within fixed limits to prevent thermal shock occurring. To ensure complete combustion, the air flow rate must be sufficient. However, the boiler efficiency will reduce if the air rate is excess. [23] Steam demand variations affect temperatures and pressures throughout the boiler.

2. Modeling of the Boiler Turbine Unit

Operators in a FFPU must satisfy two global operating requirements:

Maintain the energy balance within the unit, and generate the MW needed to satisfy the load demand. They satisfy these requirements by the BTG (Boiler-Turbine-Generator) board instrumentation, the adequate regulation of generated power, drum water level, and main steam pressure. To do so, they adjust the main steam flow, feed water flow, fuel and air flows bell and astrom model is assumed as a real plant 160MW boiler-turbine unit and is described by a third-order MIMO nonlinear state equation as follows:

$$\dot{x}_1 = -0.0018u_2x_1^{\frac{9}{8}} + 0.9u_1 - 0.15u_3 \quad (1)$$

$$\dot{x}_2 = (0.073u_2 - 0.016)x_1^{\frac{9}{8}} - 0.1x_2 \quad (2)$$

$$x_3 = \frac{141u_2 - (1.1u_2 - 0.19)x_1}{85} \quad (3)$$

The state variables x1, x2 and x3 represent drum pressure (kg/cm2), Power output in megawatts (MW), and fluid density (kg/m3), respectively. The inputs u1, u2 and u3 are the valve positions of fuel flow, steam flow control, and feed water flow, respectively. Positions of valve actuators are constrained to [0, 1], and their rates of change per second are limited to the following constraints.

$0 \leq u_i \leq 1 \quad i = 1,2,3$

$\leq \dot{u}_2 \leq 0.02$

Denote x = [x_1 x_2 x_3]T and u = [u_1 u_2 u_3]T .

The outputs of the Unit are given by:

$$y_1 = x_1 \quad (4)$$

$$y_2 = x_2 \quad (5)$$

$$y_3 = 0.05(0.1307x_3 + 100a_{cs} + \frac{q_e}{9} - 67.975) \quad (6)$$

The output y3 is the drum water level. αcs and qe are the variables of steam quality and evaporation rate (Kg/s), respectively, and they are given by:

$$\alpha_{cs} = \frac{(1+0.001538x_3)(0.8x_1-25.6)}{x_3(1.0394-0.0012304x_1)}$$

(7)

$$q_e = (0.854u_2 - 0.147)x_1 + 45.59u_1 - 2.51u_3 - 2.096 \quad (7)$$

The linear control design for the unit in the paper takes the linearized model at the operating point

$$x_0 = \begin{pmatrix} 97.2 \\ 50.52 \\ 385.2 \end{pmatrix}, \; u_0 = \begin{pmatrix} 0.271 \\ 0.621 \\ 0.36 \end{pmatrix}, \; y_0 = \begin{pmatrix} 97.2 \\ 50.52 \\ -0.32 \end{pmatrix}$$

The result of the linearization is as follows: -

$\bar{x} = A\bar{x}(t) + B\bar{u}(t)$

$\bar{y} = C\bar{x}(t) + D\bar{u}(t)$

$$A = \begin{bmatrix} -0.0022 & 0 & 0 \\ 0.0585 & -0.1 & 0 \\ -0.0058 & 0 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} 0.9 & -0.31 & -0.15 \\ 0 & 12.5732 & 0 \\ 0 & -1.2579 & 1.6588 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0.0071 & 0 & 0.0046 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0.2533 & 0.4607 & -0.014 \end{bmatrix}$$

Then, a simple algebraic operation with Laplace transform gives transfer functions as follows:

$Y(s) = [C (sI - A)^{-1}B + D]\, U(s)$

$$Y(s) = \begin{bmatrix} G11\ G12\ G13 \\ G21\ G22\ G23 \\ G31\ G32\ G33 \end{bmatrix} U(S)$$

Then the linearized model is given by following transfer function matrix G(s)

$$G_{11} = \frac{0.9}{s + .0022} \tag{8}$$

$$G_{21} = \frac{0.05265}{(s + .0022)(s + 0.1)} \tag{9}$$

$$G_{31} = \frac{0.2533(s + 0.03053)(s - 0.003105)}{s(s + 0.0022)} \tag{10}$$

$$G_{12} = \frac{-0.31}{s + .0022} \tag{11}$$

$$G_{22} = \frac{12.573(s + 0.0007576)}{(s + .0022)(s + 0.1)} \tag{12}$$

$$G_{32} = \frac{0.4607(s - .01575)(s + 0.0006145)}{s(s + .0022)} \tag{13}$$

$$G_{13} = \frac{-0.15}{s + .0022} \tag{14}$$

$$G_{23} = \frac{-0.008775}{(s + .0022)(s + .1)} \tag{15}$$

$$G_{33} = \frac{-.014(s - .4699)(s + .00316)}{s(s + .0022)} \tag{16}$$

3. Results and Simulation

The optimal control based on optimal filtering work of Wiener [10], reached maturity in the 1960s with the introduction of the Linear Quadratic Gaussian control (LQG). For the synthesis of the LQG control, it is necessary to obtain a linear model that represents the process about a given operating point. The procedure of MIGO (M – constrained integral gain optimization) is similar to that of Ziegler-Nichols method. Generally the time constant for this method is obtained by equations given by Aström and Hägglund [1] [2]. In this paper AMIGO method is implemented using the sisotool in the MATLAB/Simulink, Fig. (4), Fig. (5), shows the system response to the technique LQG, MIGO respectively.

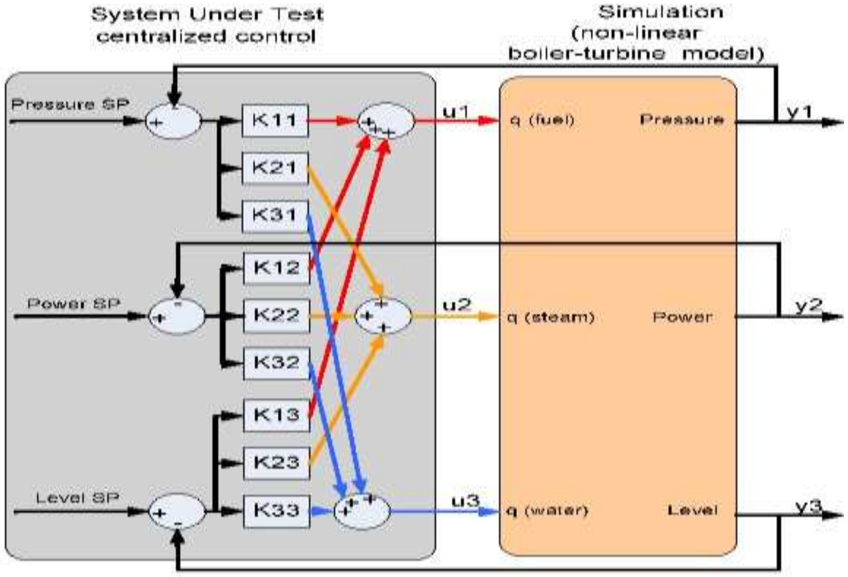

Fig 3 . Centralized control using a unity feedback control structure

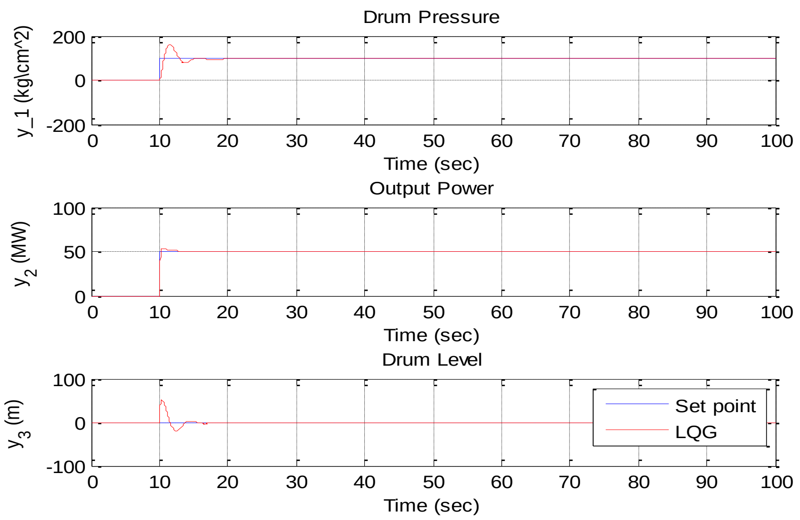

Figure 4. Responses of system from nominal operating point to a near operating point.

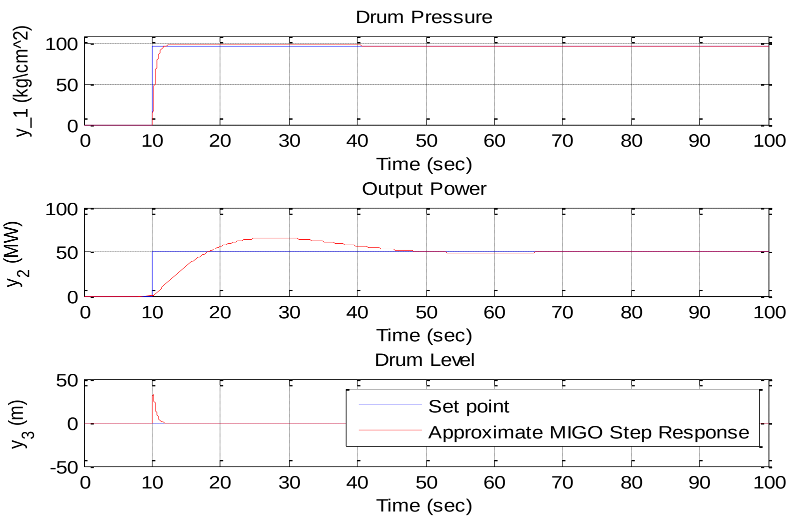

Figure 5. Responses of system from nominal operating point to a near operating point.

The nonlinearity of a boiler-turbine unit was analyzed in this paper. It was shown that the unit exhibits severe nonlinearities, and choice of a good operating range can help avoid the nonlinearity. A linear controller was designed MIGO approach, and LQG compensation the single linear controller works well in the desired operating range. It should be noted that the analysis is for the specified boiler-turbine unit. General conclusions on the operation and control of a boiler-turbine unit should be made with caution.

4. Conclusions

This paper provides an over view of fossil fuel power plant (FFPP) configuration, design, components, operation, problems during operation and control technology. An additional goal of the paper is to investigate various techniques that improve the efficiency of BTU.

Performance improvement in BTU takes different forms, such as reducing the operational and maintenance costs, reduce the fuel consumption or reducing the emission of polluting gases to the environment. This leads to more stringent requirements on the control systems for the processes. It required to keep the processes operating well for large changes in the operating conditions. One way to achieve this is incorporate control to meet the load demand of electrical power while maintaining the pressure and water level in the drum within tolerance.

This boiler-turbine system is modeled with a multi input-multi output (MIMO) nonlinear system.

In order to achieve a good performance, the control of the unit must be carried out by multivariable control strategies. In fact, the requirements to control simultaneously several measures with strong coupling, justify the use of any multivariable control. However, the choice of the model to be used for control system testing must take into account the coupling between the individual boiler subsystems.

This paper has considered the real plant of boiler turbine system model which was developed by Bell and Astrom. The model presents a 160MW oil-fired-drum-type boiler-turbine generator for overall wide range simulation and could be described by a third order MIMO nonlinear state equation. However, the changing in the load demand from time to time produces a time delay between the turbine and the boiler. This time delay may result in a bad closed-loop performance

and undesired over shoots is obtained. In order to overcome this limitation, the conventional PID control was incorporated into the design. Simulation results show that multivariable nonlinear control introduced in this paper is well done for nonlinear boiler-turbine system.

References

[1]Lasse Rantaniemi,“ Productizing of advanced service for power plants,” , *LUT School of Technology*, vol. 1, no. 1, pp. 1-77, LUTPUB. March, 2015. http://lutpub.lut.fi/bitstream/handle/10024/103770/Rantaniemi_Masters_Thesis.pdf?sequence=2

[2] ABB Ltd,, “Energy Efficient Design of Auxiliary Systems in Fossil-Fuel Power Plants,” *ABB Inc*, vol. 2, no. 1, pp. 1-358, ABB *Inc* , jun 2009 at https://library.e.abb.com/public

[3] Radu-Emil Precup, Tariq Kamal, “Solar Photovoltaic Power Plants: Advanced Control and Optimization Techniques,” *Springer,* edition , Springer 1 jun, 2019. at https://www.amazon.com

[4] Irving Granet, Maurice Bluestein, “Thermodynamics and Heat Power,” *CRC Press,* edition 16 Dec, 2019. CRC Press at https://www.amazon.com

[5] Idehai Ohijeagbon, Simeon Jekayinfa, Olumuyiwa Lasode, Adekojo Waheed “exergetic modelling of oil-fired steam boilers” *Nigerion journal of Technology,* Vol 33,pp 523-536, 04 Oct, 2014. at https://www.academia.edu

[6] Adrian Bejan , “Advanced Engineering Thermodynamics,” Wiley, 4th edition, Kindle edition . 19 Sep, 2016. Access online on 19 Dec 2018 at https://www.amazon.com

[7] H.D. Karatza, “Simulation modeling practice and theory”, Elsevier, vol. 2.0.0, no. 1, pp. 5-15, Elsevier,. 19 Aug, 2019. Access online on 19 Dec 2018. at http://www.elsevier.com/mathematics

[8] W. S. Author, “Thermoeconomic optimization of heat recovery steam generators operating parameters for combined plants. Energy,” Wiley,. March, 2004. Access online on 04 Nov 2005 at http://www.elsevier.com/locate/energy

[9] S. Skogestad , I. Postlethwaite, “Multivariable feedback control: analysis and design,” Wiley, March, 2005. Access online on 01 March 2005 at https://www.amazon.com

[10] Panagopoulas, H.,Astrom, K. J., Hagglund, T “ Min-Max optimization-based design of fractional PID controller

,” IEEE Proc.-Control Theory Appl.”, 149,pp 32-40. ,IEEE,16 April 2015 at https://ieeexplore.ieee.org

[11] Igor Boiko, ” Non-parametric Tuning of PID Controllers: A Modified Relay-Feedback-Test Approach”, Instrument Society of America, 2nd edition ,1995 at https://www.amazon.com

[12] Cheng, L.; Guo, J.I.F. and Mingtian, X.u.. “Thermodynamic analysis of waste heat power generation system. Institute of Thermal Science and Technology”, *Energy*, Vol 35,pp 2824-2835, 2010 at https://www.researchgate.net

[13] Datta, A. , Som, S.K,” Energy and exergy balance in a gas turbine combustor". J Power Energy—Proc Inst Mech Eng, 213A, 23–32, . (1999), at

[14] Drbal, L.F; Boston, P.G.; Westra, K.L. and Erickson, R.B.. “Power Plant Engineering”. *Springer*, Black & Veatech, Ist Edition , New York, 19 jun 2014, at https://www.amazon.com

[15] Kakaras, E.; Ahladas, P. and syrmopoulos, S ,” Computer simulation studies for the integration of dryer to coal power plant”. *Fuel*, Vol 81(5), pp 583-593. 2002 at https://www.researchgate.net

[16] Kaushik, S.C.; SivaReddy, V. and Tyagi, S.K. (2011). “Energy and exergy analyses of thermal power plants”. *elsiver*, Renewable and Sustainable energy reviews, vol 15, pp1857-1872, May 2011, at https://www.sciencedirect.com

[17] Kjaer, S,” The advanced supercritical 700oC pulverized coal-fired power plant”. *Elsevier*, vol 55, pp 47-49, Power Tech, 2013, https://core.ac.uk

[18] Kiga, T.; Yoshikawa, K.; Sakai, M. And Mochida, S,” Characteristics of pulverized coal combustion in high temperature preheated air”. *Journal of propulsion and power*, vol 16,issue 4, pp 601-605, Aug. 2000, at https://www.researchgate.net

[19] Kitto, J.B, ”Developments in pulverized coal-fired boiler technology”, *Babcock* & *Wilcox*. 96, 1996, at https://www.researchgate.net

[20] Lako, P. ,“Coal-fired power technologies: Coal-fired power options on the brink of climate policies” , *ECN Policy studies, Netherlands*,2004, at https://www.osti.gov

[21] Leung, P. and Moore, R.E,Closure to discussion of cycles for supplying steam to desalting evaporators of dual-purpose power-generation plants. *ASME*., vol 88, pp 283, Eng. Power ,1966 at https://asmedigitalcollection.asme.org

[22] Li, Y. and Liu, L. "Exergy analysis of 300 MW coal-fired power plant. International Conference on future Electrical Power and energy systems", *elsiver*, vol 17, pp926- 932, Energy Procedia ,2012, at https://core.ac.uk

[23] Lior, N. and Zhang, N,, "exergy and second law performance criteria", *elsiver*, vol 32,Issue 3,pp 281-296,Energy,April 2007 at https://www.sciencedirect.com