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Optimization of reheat-pressure ratios in Supercritical, Ultra Supercritical and advanced ultra-supercritical Thermal Power Plants with Single Reheating

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Abstract: This research paper presents the thermodynamic analysis of a modern supercritical (SC), ultra supercritical (USC) and advanced ultra supercritical (AUSC) steam power plants with a power generating capacity of 1200 MW, employing with single re-heat configuration. A MATLAB software code has been developed to accurately estimate the steam properties under varying conditions. The study focuses on the temperature and pressure at the turbine's inlet and outlet. The cycle's energy efficiency and exergy efficiency have been thoroughly examined, along with the impact of single reheat pressure on the cycle's performance. It has been observed that both efficiencies exhibit a more pronounced increase with rising temperatures compared to increasing pressures. The exergy losses incurred in each of the cycle's components have been meticulously studied and analyzed by systematically varying the pressure ratios of SC, USC and AUSC power plants.

Keywords: Supercritical cycle, cycle efficiency, exergy efficiency, fractional exergy loss

1. Introduction

Steam Reheating is an important process in order to maintain the steam quality to more than 0.85 dryness fraction, and used in conventional steam-power plants. The steam after partly expanded would be sent back to the steam generator to increase the turbine inlet temperature at the next stage of turbine expansion. Doing so the net work output and the thermal efficiency of the steam power plant could be attained. The reheat pressure ratio and reheat temperature ratios plays considerable impact on the network output and life of the turbine blades. The possible reheat pressure ratios and reheat temperature ratios could be studied and optimized for the better performance. Major source of power generation across the globe as well as in India is from the coal combusted power plants. Societal and economic development is only possible by conserving the energy. By adopting the supercritical technology, we could conserve a greater amount energy which also helps to attain the reduced emissions to the atmosphere. Using the steam above critical point enables to attain higher power plant efficiencies also lowers fuel consumption significantly reduces the emissions for the same amount of power generation.

Exergy analysis is the method of analyzing the energy transformation or conversion which could be calculated based on available/potential quantity of fuel energy. An exergy analysis is carried out for the selected coal combusted supercritical thermal power plant which is focused on the energy convertibility / potential to convert during all the individual processes.

The supercritical cycle is inherited from the basic Rankine cycle and analyzed by E.G. Feher[1], for the preliminary comparison. Kotas [2] described the exergy and enthalpy for the inlet and exit flue gas parameters into the steam generator. And also the variations in chemical compositions in anthracite coal also has been considered by Kotas. Kotas [8] described and explained the nomenclature of the exergy terms and employed for the exergy analysis. In order to calculate the properties of water/steam at supercritical conditions the mathematical models have been developed by W. C. J. D. A. K. J. K. H. K. A. Wagner [4]. The introductory principles of thermodynamics which could be used to analyse the thermodynamic cycles have been explained by P.K. Nag, Moran Shapiro, Bejan, Moran and Cengel. Habib [6] in his publication demonstrated the importance of the reheat in the steam power generation. Rayudu [13] in his publication investigated on supercritical power cycles with single and double reheating.

Analysis of thermal power plants by means of the cycle efficiency is a prominent topic in the mechanical engineering. The exergy analysis provides convertibility of the energy and the corresponding efficiency of the supercritical cycle, where as the conventional energy method gives overall efficiency value which is based on first law of thermodynamics. The steam which is the vapour form of water is the working fluid which is used in vapor power cycles. The water is having the desirable characteristics of the working medium that could be used in Rankine cycle. Few required characteristics are abundant availability, reusability, enthalpy of vaporization and low cost. Steam power plants are commonly coal combusted power plants, nuclear power plants, geothermal or natural gas plants. In all these power plants the source is heat given to the water would be different and the working medium would be the vapour form of water which could be used in all these basic cycles. Therefore, all these power plants could be analyzed by using the exergy and energy techniques.

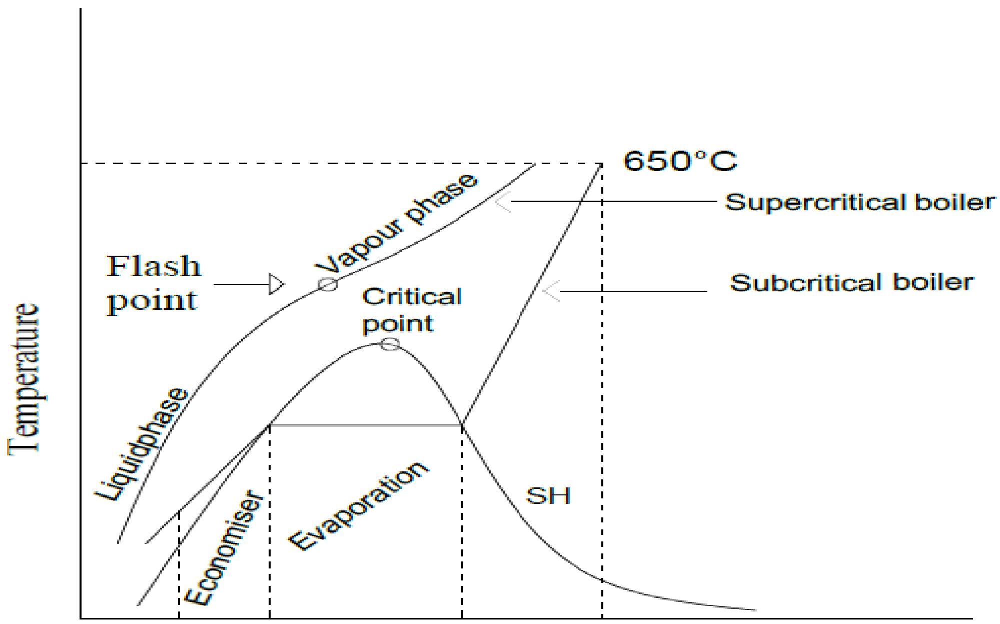

Fig 1: Demonstration of supercritical heating and subcritical heating

This research paper analyses a supercritical (SC), Ultra supercritical (USC), and Advanced ultra supercritical (AUSC) steam cycles emphasizing the exergy by it application with single reheat. The effect of variation in pressure ratios on energy and exergy efficiency is investigated for SC, USC, and AUSC power plants.

2. Supercritical (SC), Ultra Supercritical (USC) And Advanced Ultra Supercritical (AUSC) Cycle Description

The layout of the power plant which is proposed to study is illustrated below. It is comprising of a once through boiler, turbines, condenser, feedwater heaters, reheating system and pumps and are arranged as shown in fig. The working principle is described below.

The condensate which leaves the condenser is heated in low pressure feedwater heaters by utilizing the steam extractions at various points. It is then circulated through the deaerator in order to remove the dissolved gasses and also a little temperature rise. Then this feedwater passes through the high pressure feedwater heater, then given to the economizer. Once the feedwater obtains the desired temperature and pressure it would be supplied to the supercritical boiler or once through boiler. The supercritical steam would be fed into the high pressure turbine and gets expanded till the reheat pressure. Then the exhaust steam from the high pressure turbine would be taken into the boiler to rise its temperature to desired level. The reheated steam is given to the intermediate pressure turbine gets expanded to certain pressure and then given to the low pressure turbine for further expansion. Finally, the expanded steam is supplied to the condenser in which its phase will be changed to liquid phase.

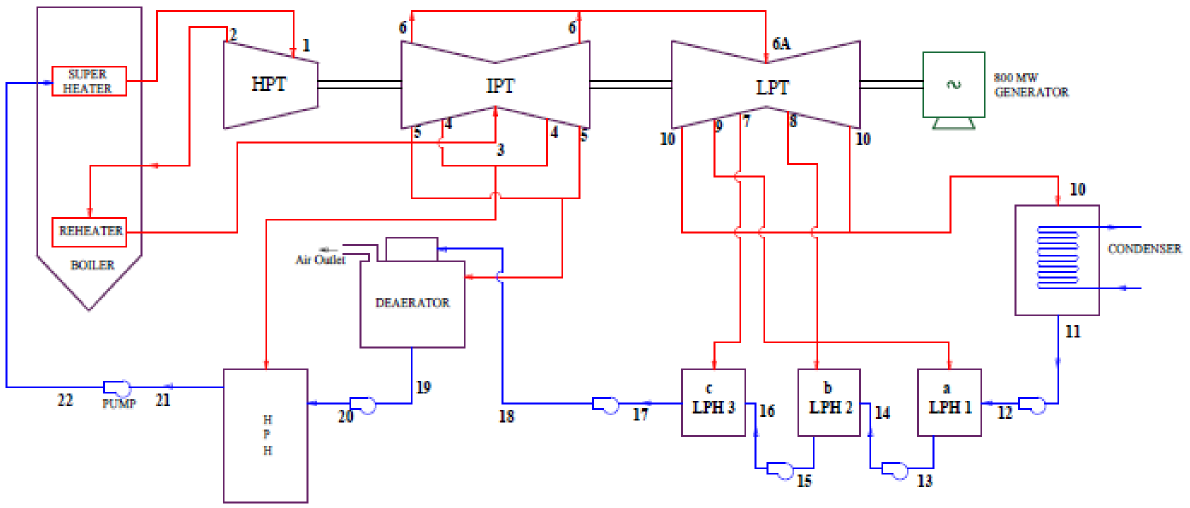

Fig 2: Schematic diagram of the SC,USC, AUSC cycle with single reheat

3. Assumed Scenario For The Power Plant Analysis

1. Capacity of the supercritical power plant = 1200 MW
2. The inlet turbine temperatures in the range of 500^{O}C – 800^{O}C
3. The inlet turbine pressures are in the range of 221bar – 350 bar
4. Reheat pressure ratio assumed is 0.1 – 0.5 times the initial pressure
5. No heat losses from the individual and no pressure losses
6. Isentropic efficiency of the steam turbine is 85%.
7. Cumulative Pump efficiency is assumed to be 85%.
8. Condenser pressure P_c= 0.03 –0.08 bar
9. Cooling water temperature inlet to the condenser T_{wi}=28^{0}C
10. The flue gas inlet temperature to the boiler is in the range of 900^{O}C to 1400^{O}C

4. Exergy Analysis

The Governing Exergy and Energy Equations used in the computational model Supercritical/Ultra Supercritical/Advanced Ultra Supercritical Power plant with varying number of feedwater heaters:

As can be seen from the Figure2 the number of feed water heaters is left as a variable parameter ‘n’ and thus the both the number feed water heaters as well as the number of stations at which properties are monitored in the plant are also variables. The numbering of the stations is done in such a way that starting from the first feed water heater, consecutive numbers are assigned to the steam bleed, the feed water heater exit, which is also the inlet for the feed pump which follows that heater, and the exit of the said feed pump. Thus station 1 and 2 are the steam bleed and exit stream of the feed water heater 1, station 4 in the feed water inlet (also the exit from and station 3 is the exit of the first feed pump which is also the inlet to the boiler. For an intermediate feed water heater ‘i’ the steam bleed will be from station ‘3i-2’, water inlet will be from station ‘3i+3’ and exit will be station ‘3i-1’. Similarly, for feed water heater ‘i’, the inlet and exit are ‘3i-1’ and ‘3i’, respectively. In addition, the turbine inlet, re-heater inlet, re-heater exit, turbine exit, and condenser exit are termed as stations ‘A’, ‘B’, ‘C’, ‘D’, ‘E’,’F’, and ‘G’ respectively.

The governing equations for each of the components in the steam power plant could be derived from the general steady flow mass, energy and exergy equations for a control volume given by Moran and Shapiro [7] as:

$$\Sigma_i m_i = \Sigma_e m_e \quad (1)$$

$$\dot{Q}_{cv} + \sum_i m_i \left(h_i + \frac{V_i^2}{2} + z_i g\right) = \dot{W}_{cv} + \sum_e m_e \left(h_e + \frac{V_e^2}{2} + z_e g\right) \quad (2)$$

$$\sum_j \left(1 - \frac{T_0}{T_j}\right) \dot{Q}_{CV,j} + \sum_i m_i \mathbf{e}_{f,i} = \dot{W}_{cv} + \sum_e m_e \mathbf{e}_{f,e} + \dot{\mathbf{E}}_d \quad (3)$$

Here $\mathbf{e}_f$ is the specific flow exergy which is defined as:

$$\mathbf{e}_f = (h - h_0) + T(s - s_0) + \frac{V^2}{2} + gz \quad (4)$$

In all the components of the cycle, the kinetic and potential energy changes could be neglected. The specific equations for the each of the individual components are given below.

Boiler

Here only the water tube banks of the boiler are taken as the system. Thus the system becomes a single inlet single outlet control volume. Also, there is no work interaction in the boiler. With these assumptions and the notations given in the figure A the following equations are obtained for the boiler.

$$\dot{Q}_{boiler} = m_A(h_A - h_3) + m_B(h_C - h_B) \quad (5)$$

$$\dot{\mathbf{E}}_{d,boiler} = \left(1 - \frac{T_0}{T_{boiler}}\right) \dot{Q}_{boiler} + m_A(\mathbf{e}_{f,A} - \mathbf{e}_{f,3}) + m_B(\mathbf{e}_{f,C} - \mathbf{e}_{f,B}) \quad (6)$$

Turbine

The mass, energy and exergy equations for the turbine could be written as:

$$m_1 = m_3 + \sum_{l=1}^{n} m_{3l-2} \quad (7)$$

$$\dot{Q}_{turb} = m_A h_A + m_C h_C - m_B h_B - m_B h_B - \sum_{l=1}^{n} m_{3l-2} h_{3l-2} \quad (8)$$

$$\dot{\mathbf{E}}_{d,turb} = \left(1 - \frac{T_0}{T_{turb}}\right) \dot{Q}_{turb} + m_A \mathbf{e}_{f,A} + m_C \mathbf{e}_{f,C} - m_B \mathbf{e}_{f,B} - m_D \mathbf{e}_{f,D} - \sum_{l=1}^{n} m_{3l-2} \mathbf{e}_{f,3l-2} - \dot{W}_{turb} \quad (9)$$

Condenser

As was done in the case of the boiler, only the hot fluid circuit in the condenser is analyzed as the system of interest. With the usual assumptions, the energy and exergy equations for the condenser could be written as

$$\dot{Q}_{cond} = m_D h_D - m_E h_E \quad (10)$$

$$\dot{\mathbf{E}}_{d,cond} = \left(1 - \frac{T_0}{T_{cond}}\right) \dot{Q}_{cond} + m_D \mathbf{e}_{f,D} - m_E \mathbf{e}_{f,E} \quad (11)$$

Feed Water Heaters

The mass conservation equation for any feed water ‘i’ is given by:

$$m_{3i-2} + m_{3i+3} = m_{3i-1} \quad (12)$$

The energy equation for the feed water heater ‘i’ is:

$$m_{3i-2}h_{3i-2} + m_{3i+3}h_{3i+3} = m_{3i-1}h_{3i-1} \quad (13)$$

The exergy equation is:

$$\dot{\mathbf{E}}_{d,Hi} = m_{3i-2}\mathbf{e}_{\mathrm{f},3i-2} + m_{3i+3}\mathbf{e}_{f,3i+3} - m_{3i-1}\mathbf{e}_{f,3i-1} \quad (14)$$

Pumps

For any feed pump 'i' other than the last feed water heater is, the energy and exergy equations are

$$W_{pump\ i} = m_{3i-1}(h_{3i} - h_{3i-1}) \quad (15)$$

$$\dot{\mathbf{E}}_{d,pump\ i} = m_{3i-1}(\mathbf{e}_{f,3i} - \mathbf{e}_{f,3i-1}) - W_{pump\ i} \quad (16)$$

The mass, energy and exergy equations for the last feed pump are given respectively by:

$$W_{pump\ n+1} = m_E(h_{3n-1} - h_E) \quad (17)$$

$$\dot{\mathbf{E}}_{d,pump\ n+1} = m_E(\mathbf{e}_{f,3n-1} - \mathbf{e}_{f,E}) - W_{pump\ n+1} \quad (18)$$

Overall Performance

The net amount of work generated in the power plant is given by:

$$W_{plant} = W_{turb} - \sum_{l=1}^{n+1} W_{pump\ i} \quad (19)$$

The efficiency of the plant can be calculated as:

$$\eta_{plant} = \frac{W_{plant}}{\dot{Q}_{boiler}} \quad (20)$$

The exergy efficiency of the plant is given by:

$$\eta_{plant} = \frac{W_{plant}}{\left(1 - \frac{T_0}{T_{boiler}}\right)\dot{Q}_{boiler}} \quad (21)$$

The total exergy destruction in the plant is given by:

$$\dot{\boldsymbol{E}}_{d,plant} = \sum_{all\ components} \dot{\boldsymbol{E}}_d \quad (22)$$

MATLAB Code for the model: A computer code was developed using the scripting language MATLAB to solve the model equations given above. The code is written such that it takes the turbine inlet temperature and the pressure ratios for various stages of expansion as the input and calculates the mass, energy and exergy balances for each of the components to determine the thermodynamic performance characteristics of various components in the system. The amount of steam taken from each bleed is computed by assuming that in each feed water heater the condensate is heated to the saturation temperature at the corresponding pressure. Isentropic efficiencies of the turbines are assumed to be 85%. The net work output of the cycle is then computed. The mass flow rate of steam in the power plant is computed based on the total power generated by the plant and the specific work output of the cycle. Energy and exergy losses in each of the components are then estimated. The reheat pressure ratio and the reheat temperature are also given as input parameters and their effect on the cycle performance is analyzed.

5. RESULTS AND DISCUSSION

The parametric study and thermodynamic analysis is performed for this simulated model power plant of Supercritical/Ultra Supercritical /Advanced Ultra Supercritical with single reheater. The energy and exergy analysis for all the considered scenario's are carried out and presented below.

The operating conditions for Supercritical, Ultra Supercritical and advanced Ultra Supercritical power plants are taken from the national electricity plan released by central electricity authority of Government of India [1]. The range of operating parameters considered for this study are listed below table.

Technology	Turbine inlet pressure	Turbine inlet temperature
Supercritical (SC) power plant	221 bar to 250 bar	500^{O} C to 600^{O} C
Ultra Supercritical (USC) power plant	251 bar to 300 bar	550^{O} C to 700^{O} C
Advanced Ultra Supercritical (AUSC) power plant	301 bar to 350 bar	700^{O} C to 800^{O} C

Supercritical power plant with single reheating:

The power plant simulated model for supercritical power plant scenario was run by varying pressure ratios ranging from 0.1 to 0.5. And the results were tabulated as given below.

Energy Analysis:

R	Wt(KJ/Kg)	Wp(KJ/Kg)	Wnet(KW)	HS(KJ/sec)	EnEff	Ms(Kg/sec)
0.1	1577.86	30.112	784733	1.79E+06	43.88	507.015
0.14	1521.09	30.6989	783854	1.77E+06	44.28	525.937
0.18	1469.01	31.1896	783015	1.76E+06	44.5	544.585
0.22	1420.52	31.6161	782195	1.75E+06	44.6	563.173
0.26	1374.83	31.9955	781382	1.75E+06	44.64	581.888
0.3	1331.36	32.3372	780569	1.75E+06	44.63	600.89
0.34	1289.69	32.6455	779750	1.75E+06	44.59	620.303
0.38	1249.5	32.921	778922	1.75E+06	44.52	640.258
0.42	1210.49	33.1619	778084	1.75E+06	44.42	660.889
0.46	1172.46	33.3648	777234	1.75E+06	44.31	682.327
0.5	1135.2	33.5259	776374	1.76E+06	44.18	704.723

The Figure3, shows the trends of how the overall thermal efficiency of the Supercritical power plant changes with reheat pressure ratio and turbine inlet temperature as the varying parameters while all the other conditions are held constant. The reheat pressure is varied in the range between 10 % of the boiler pressure to 50 % of the boiler pressure. The turbine inlet temperatures are varied between 500 ºC and 600 ºC, keeping the turbine inlet pressure 240 bar and condenser pressure of 0.04 bar constant. Separate energy efficiency vs. reheat pressure ratio curves are plotted for each value of the turbine inlet temperature in **Error! Reference source not found.**. It can be seen from this figure that at each turbine inlet temperature there is an optimum value for the reheat pressure ratio at which the thermal efficiency of the plant is maximum and for any other pressure ratio which is greater than or less than this optimum value, the thermal efficiency decreases.

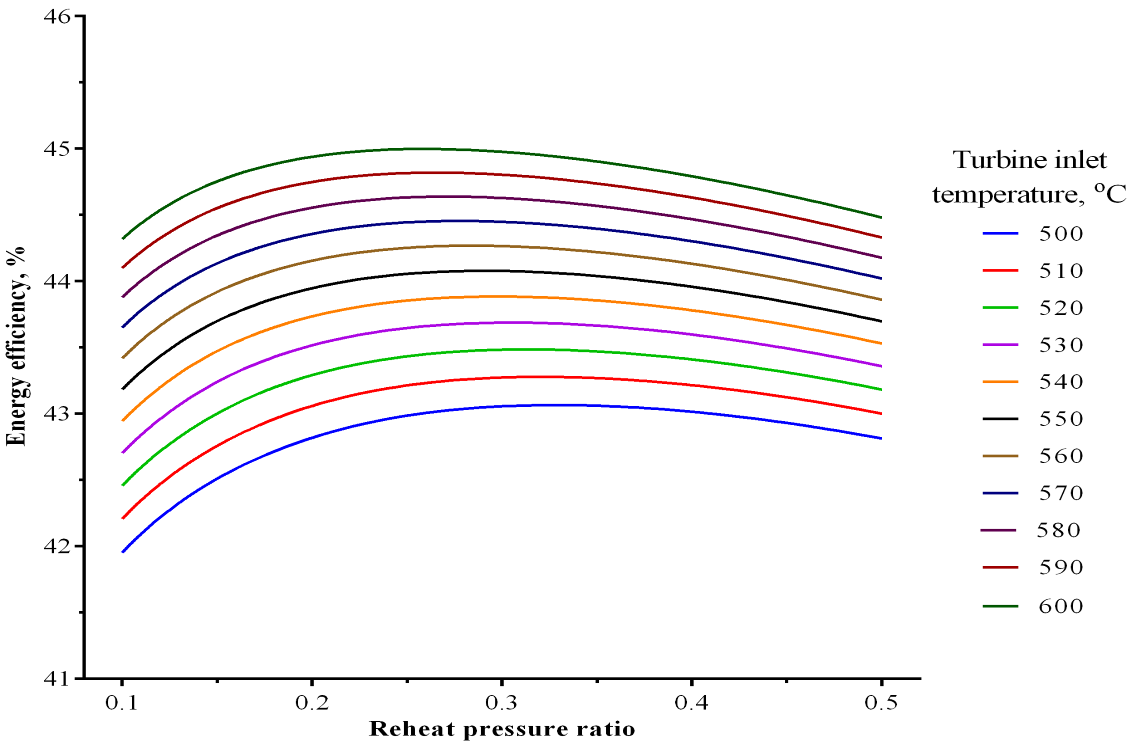

Fig 3: Impact of reheat pressure ratio on energy efficiency – for Supercritical operating parameters

The maximum efficiency (which is observed at the optimum reheat pressure ratio) has increased from 43.06% to 45% when the turbine inlet temperature is changed from 500 ºC to 600 ºC. Also, it is noteworthy that the optimum value of reheat pressure ratio is different at different turbine inlet temperatures: decreasing from 0.328 for a turbine inlet temperature of 500 ºC to 0.26 at 600 ºC. In other words, while the thermal efficiency is increasing with temperature at all the reheat pressure ratios, the increase is rather non-uniform which causes the optimum reheat pressure (i.e. the pressure at which the thermal efficiency is maximum) to decrease with increasing turbine inlet temperature.

Exergy Analysis: The following table is provides the data or details of exergy calculations

R	Exlb (KW)	Exlt (KW)	Exlc (KW)	Exlp (KW)	Exlwh (KW)	Exlda (KW)	Exltot (KW)	ExEff
0.1	366939	82846.2	14984.6	1128.56	11342.1	7286.77	484528	64.04
0.14	351476	82430.6	14703.2	1170.26	16042.5	6215.18	472038	64.61
0.18	340879	82513.6	14548.7	1194.37	20613.5	5521.39	465271	64.91
0.22	333065	82824.7	14464.1	1202.34	25055.9	5046.7	461659	65.06
0.26	327041	83266.7	14423.5	1200.48	29391.6	4712.99	460037	65.12
0.3	322278	83790.8	14413.6	1195.86	33643.9	4476.46	459798	65.11
0.34	318448	84355.3	14425.8	1194.55	37831.9	4309.33	460565	65.05
0.38	315347	84947.2	14455.4	1201.02	41973.5	4194.51	462118	64.95
0.42	312837	85563	14499.3	1217.92	46085.2	4120.06	464323	64.82
0.46	310822	86197.4	14555.5	1246.22	50181.9	4078.46	467081	64.66
0.5	309233	86854.4	14622.6	1285.62	54278.9	4065.31	470340	64.48

Figure 4, given below demonstrates the variations in exergy efficiency of the supercritical power plant with reheat pressure ratio at various turbine inlet temperatures by keeping turbine inlet pressure and condenser pressure constant. The reheat pressure ratio is varied from 0.1 to 0.5. Separate exergy efficiency versus reheat pressure ratio curves are plotted for each value of the turbine inlet temperature.

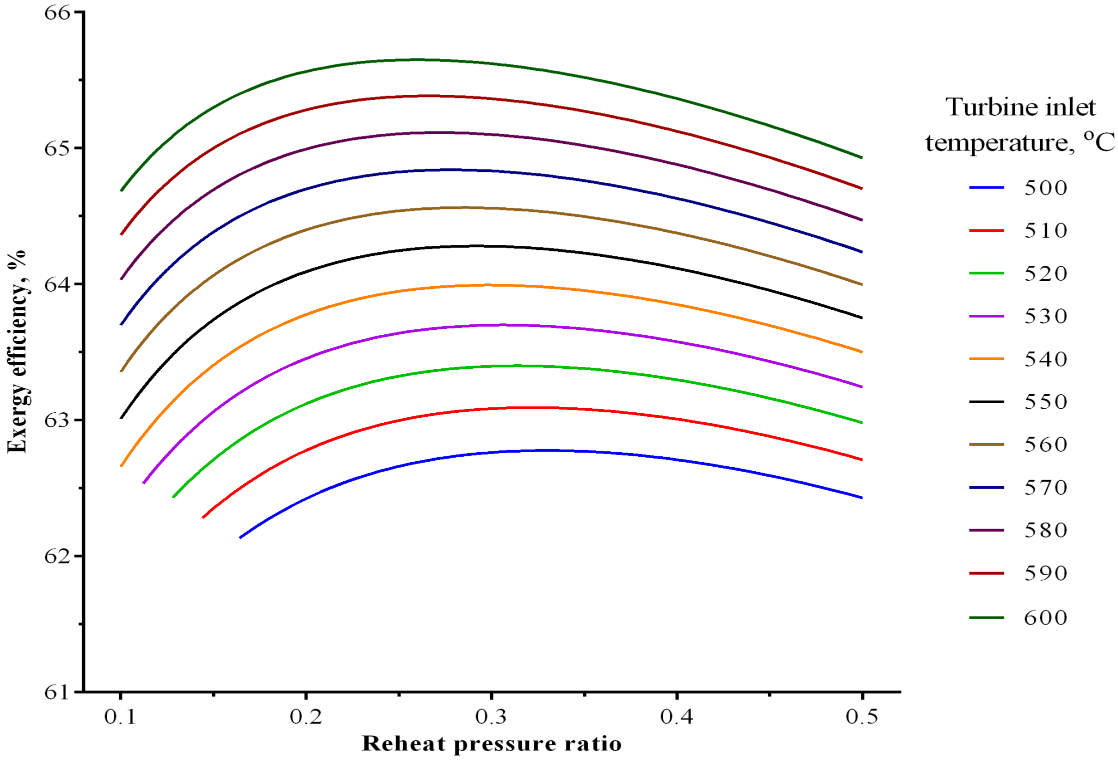

Fig 4: Impact of reheat pressure ratio on exergy efficiency – for Supercritical operating parameters

It can be observed that in this figure 4 that, at each turbine inlet temperature there is an optimum value of pressure ratio at which over all exergy efficiency of the plant is maximum. And any other pressure ratio less than or greater than that optimum value, the exergy efficiency decreases. The maximum exergy efficiency (at optimum pressure ratio) is increased from 62.77% to 65.65% and the optimum pressure ratios varied between 0.26 to 0.3, when the turbine inlet temperature varied from 500 ºC to 600 ºC. Also, it could be noted that the optimum value of pressure ratio is different at different inlet temperatures of the turbine. Also the maximum exergy efficiencies (for each turbine inlet temperature) are varying non-uniformly and also can be observed the reduction in pressure ratio, when turbine inlet temperature reaches 600 ºC.

Ultra Supercritical (USC) power plant with single reheating:

The power plant simulated model for ultra supercritical (USC) power plant scenario was run by varying pressure ratios ranging from 0.1 to 0.5. And the results were demonstrated using the graphs.

Energy Analysis for USC Power plant with single reheating.

The Figure5 given below shows the trends of how the overall thermal efficiency or energy efficiency of the Ultra Supercritical power plant changes with reheat pressure ratio and turbine inlet temperature as the varying parameters while the turbine inlet pressure (280 bar) and condenser pressure (0.04 bar) are held constant.

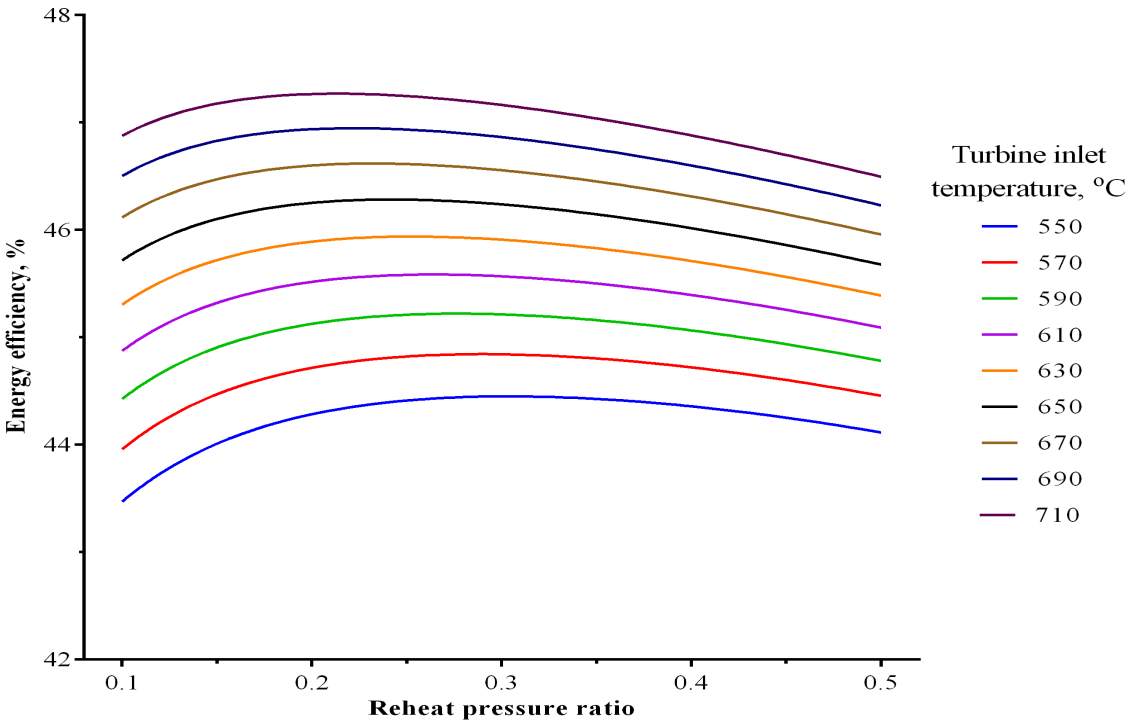

Fig 5: Impact of reheat pressure ratio on energy efficiency – for Ultra Supercritical operating parameters

The reheat pressure is varied in the range between 10 % of the boiler pressure to 50 % of the boiler pressure. The turbine inlet temperatures are varied between 550 ºC and 710 ºC, keeping the turbine inlet pressure 280 bar and condenser pressure of 0.04 bar constant, as this parametric range falls under Ultra Supercritical power plant. Separate energy efficiency vs. reheat pressure ratio curves are plotted for each value of the turbine inlet temperature in **Error! Reference source not found.**. It can be seen from this figure that at each turbine inlet temperature there is an optimum value for the reheat pressure ratio at which the thermal efficiency of the plant is maximum and for any other pressure ratio which is greater than or less than this optimum value, the thermal efficiency decreases. The maximum efficiency (which is observed at the optimum reheat pressure ratio) has increased from 44.45% to 47.26% when the turbine inlet temperature is changed from 550 ºC to 710 ºC. Also, it is noteworthy that the optimum value of reheat pressure ratio is different at different turbine inlet temperatures: decreasing from 0.3 for a turbine inlet temperature of 550 ºC to 0.21 at 710 ºC. In other words, while the thermal efficiency or energy efficiency is found increased with the temperature at all the reheat pressure ratios, the increase is rather non-uniform which causes the optimum reheat pressure ratio (i.e. the pressure ratio at which the thermal efficiency is maximum) to decrease with increasing turbine inlet temperature.

Exergy Analysis for USC Power plant with single reheating.

Figure6 below demonstrates the variations in exergy efficiency of the ultra supercritical power plant with reheat pressure ratio at various turbine inlet temperatures by keeping turbine inlet pressure(280bar) and condenser pressure(0.04 bar) constant.

The reheat pressure ratio is varied from 0.1 to 0.5. Separate exergy efficiency versus reheat pressure ratio curves are plotted for each value of the turbine inlet temperature in **Error! Reference source not found.**. It can be observed that in this figure that, at each turbine inlet temperature there is an optimum value of pressure ratio at which over all exergy efficiency of the plant is maximum. And any other pressure ratio less than or greater than that optimum value, the exergy efficiency decreases.

The maximum exergy efficiency (at optimum pressure ratio) is increased from 64.81% to 69.01% for the optimum pressure ratios of 0.212 to 0.304, when the turbine inlet temperature varied from 550 ºC to 710 ºC.

Also, it could be noted that the optimum value of pressure ratio is different at different inlet temperatures of the turbine.

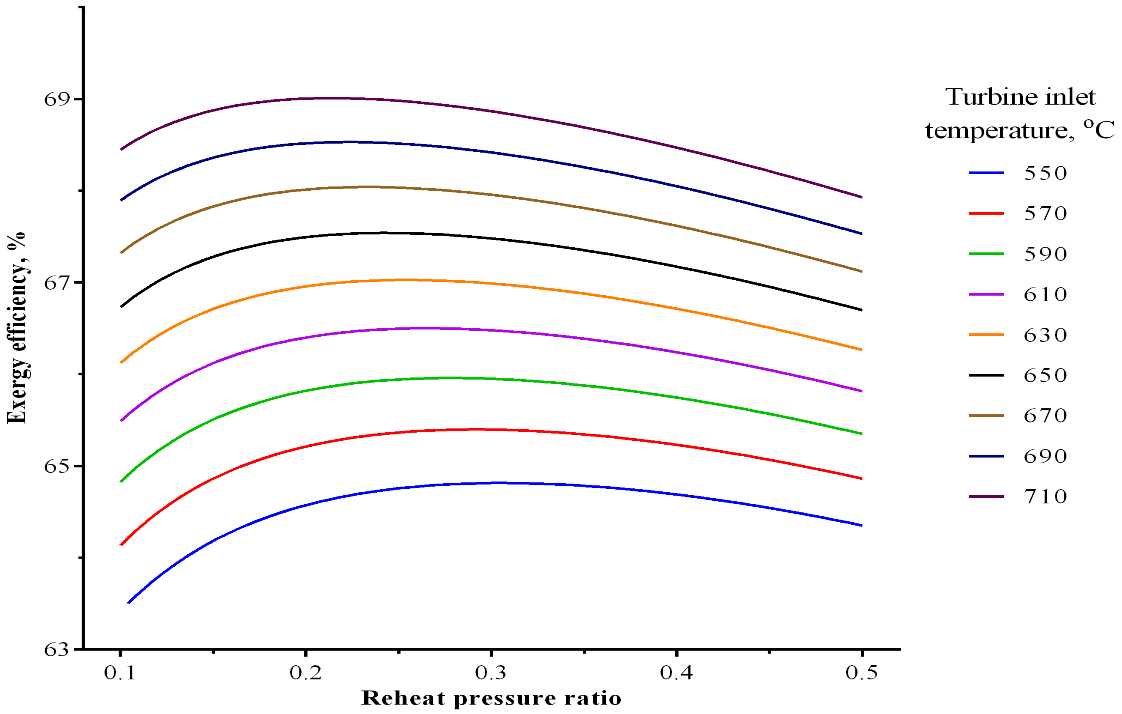

Fig 6: Impact of reheat pressure ratio on exergy efficiency – for Ultra Supercritical operating parameters

Also the maximum exergy efficiencies (for each turbine inlet temperature) are varying non-uniformly and also can be observed the reduction in pressure ratio, when turbine inlet temperature reaches 710 ºC.

Advanced Ultra Supercritical (AUSC) power plant with single reheating:

The power plant simulated model for ultra supercritical (USC) power plant scenario was run by varying pressure ratios ranging from 0.1 to 0.5. And the results were demonstrated using the graphs.

Energy Analysis for AUSC Power plant with single reheating:

Figure 7 shows the path of how the overall thermal efficiency of the advanced ultra Supercritical power plant changes with reheat pressure ratio and turbine inlet temperature as the varying parameters while all the other conditions are kept constant.

The reheat pressure is varied in the range between 10 % of the boiler pressure to 50 % of the boiler pressure. The turbine inlet temperatures are varied between 700 ºC and 800 ºC, keeping the turbine inlet pressure 320 bar and condenser pressure of 0.04 bar constant. Separate energy efficiency vs. reheat pressure ratio curves are plotted for each value of the turbine inlet temperature. It can be seen from this figure that at each turbine inlet temperature there is an optimum value for the reheat pressure ratio at which the thermal efficiency of the plant is maximum and for any other pressure ratio which is greater than or less than this optimum value, the thermal efficiency decreases.

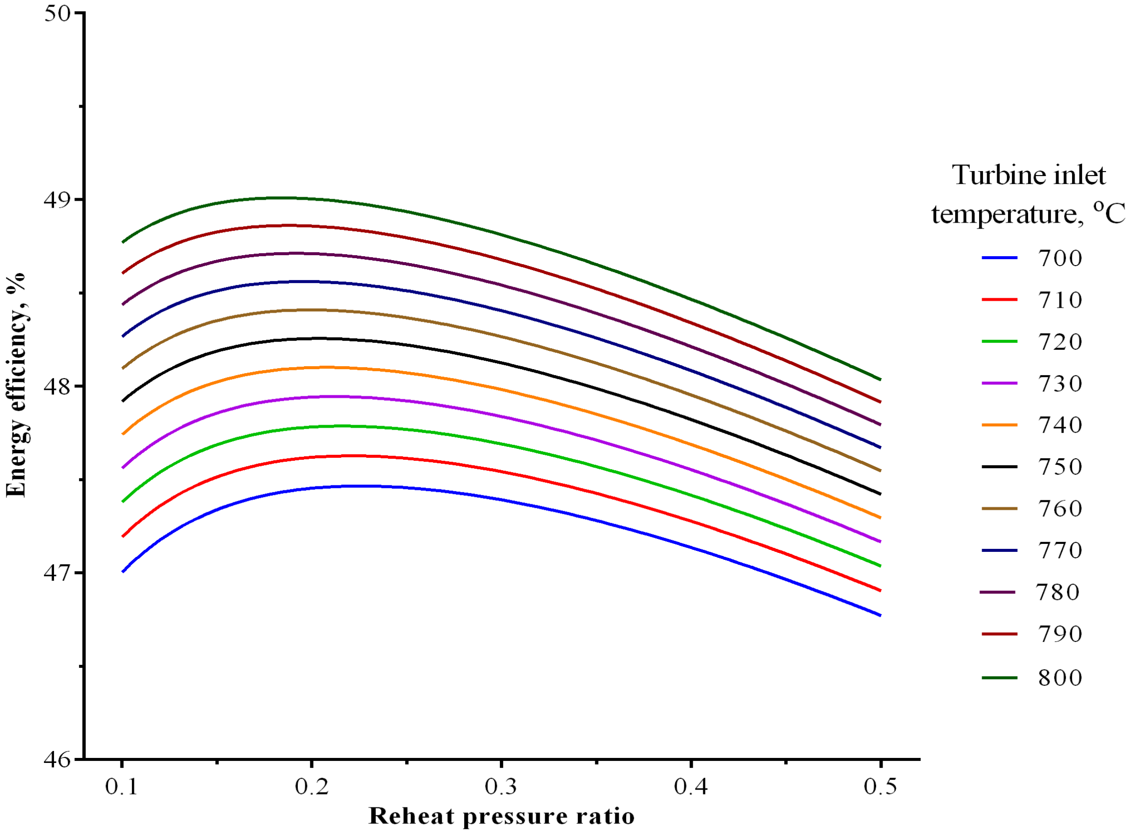

Fig 7: Impact of reheat pressure ratio on energy efficiency – for Advanced Ultra Supercritical operating parameters

The maximum energy efficiency (which is considered as the optimum reheat pressure ratio) has increased from 47.66% to 49.01% when the turbine inlet temperature is changed from 700 ºC to 800 ºC. Also, it is noteworthy that the optimum value of reheat pressure ratio is different at different turbine inlet temperatures: decreasing from 0.224 for a turbine inlet temperature of 700 ºC to 0.184 at 800 ºC. In other words, while the thermal efficiency is increasing with temperature at all the reheat pressure ratios, the increase is rather non-uniform which causes the optimum reheat pressure (i.e. the pressure at which the thermal efficiency is maximum) to decrease with increasing turbine inlet temperature.

Exergy Analysis for AUSC Power plant with single reheating:

Error! Reference source not found. demonstrates the variations in exergy efficiency of the advanced ultra supercritical power plant with reheat pressure ratio at various turbine inlet temperatures by keeping turbine inlet pressure and condenser pressure constant.

The reheat pressure ratio is varied from 0.1 to 0.5. Separate exergy efficiency versus reheat pressure ratio curves are plotted for each value of the turbine inlet temperature. It can be observed that in this figure that, at each turbine inlet temperature there is an optimum value of pressure ratio at which over all exergy efficiency of the plant is maximum. And any other pressure ratio less than or greater than that optimum value, the exergy efficiency decreases.

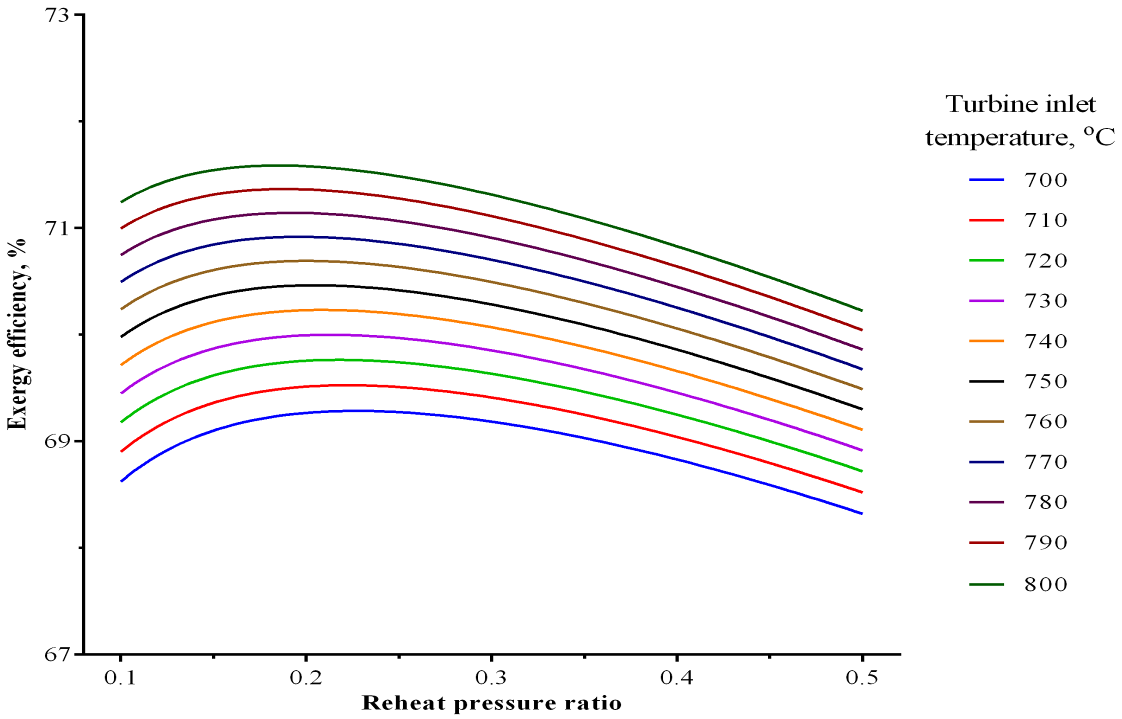

Fig 8: Impact of reheat pressure ratio on energy efficiency – for Advanced Ultra Supercritical operating parameters

The maximum exergy efficiency (at optimum pressure ratio) is increased from 69.29% to 71.58% between the pressure ratio of 0.184 and 0.228, when the turbine inlet temperature varied from 700 ºC to 800 ºC. Also, it could be noted that the optimum value of pressure ratio is different at different inlet temperatures of the turbine. Also the maximum exergy efficiencies (for each turbine inlet temperature) are varying non-uniformly and also can be observed the reduction in pressure ratio, when turbine inlet temperature reaches maximum.

6. Conclusion

This paper analyzed the supercritical (SC), ultra supercritical (USC), and advanced ultra supercritical (AUSC) power plant cycles with single reheat in a terms of energy efficiency and exergy efficiency. The energy losses and exergy losses were calculated for all these power plant scenarios with single reheat. It is observed that the power plant efficiency is being increased with increase in pressure ratio for the all the ranges of supercritical, ultra supercritical and advanced ultra supercritical power plants with single reheat. It is also concluded that exergy efficiency is maximum for the advanced ultra supercritical operating parameters than the USC and SC. The exact critical reheat pressure ratios were found, observed and calculated for SC, USC and AUSC power plants which would be one key parameter to improve the efficiency of power plants.

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