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Aging influence on the performance of the steam power units in Kuwait- case study; Doha west power station

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Abstract: This study aims to the impact of aging steam power stations on the performance of the components of the station after 30 years from the age of steam power station and at different loads, a 50%, 75% and 100% of the maximum load. In this study exergy analysis to calculate the ratio of the rate of destruction in the steam unit components. The study revealed that the largest proportion of the destruction was 11.92% annual in evaporators at load 70%, and 10.64% annual at 50% of maximum load. While the percentage of the destruction in the boiler feed water pumps was 3.25% at load 50% of the maximum load of the unit steam and the highest value at load 100% was 4.17%. The maximum rate of destroyed in economizer is 5.59 % at load70% of full load and minimum is 2.68% at 100%of load. The minimum annual destruction rate in the super heater is 4.17% at load 50%, and the maximum annual destruction rate is 8.23% at load 70% of maximum load. Also The study showed that the maximum ratio destruction in reheater when carrying load is 50% with a rate of destruction reached 6.71%, while the lowest rate of destruction of 2.76% at full load. High pressure turbine maximum distraction rate percentage is 5.5% at load 50% and minimum is 1.35% at load 75% , Intermediate pressure turbine maximum destruction rate is 2.86% at load 75% and minimum is 2.98% at load 100% , Low pressure turbine destruction rate are 4.17 and 2.98% at load 100 and 50% respectively , High pressure heaters distraction rate percentage are 4.1% and 2.76% at load 50% and 70% respectively and low pressure heaters maximum distraction rate percentage is 5.52% at load 100% and minimum is 3.77% at load 50% . The results generally showed that destruction increased with increased operation time. It was observed that deterioration and obsolescence may be the major problems and that plant rehabilitation is feasible solution.

Keywords: Dustrucation rate , Doha west , power station . Exergy , maximum Load , minmum

1. Introduction

The electrical energy is the essential foundation up on which modern civilization depends, where intervention in various aspects of daily life for all sectors. The work in the electrical power plants based on the use of large quantities of oil, which represents the first and main source of the national income of the state that the use of vast quantities of oil in power plants is a burden great on the annual budget of state. Restructured and liberalized power sector promote increased competition through unbundling of generation, transmission and privatization of distribution or retailing function .Decentralization requires the existing power plants to improve their performance in order to attain high thermal efficiency and reliability, so as to operate at low generation cost. To improve the performance of the plant, first it is necessary to find out the equipment / locations where losses are more .Destroyed analysis is provides the tool for the clear distinction between energy losses to the environment and internal irreversibility of the process. As the large change of the grid load many large capacity in Kuwait where consumption level of people have enhanced , which leads to large proportion of electricity power is consumed in our daily life , resulting in the difference between peak and minimum of grid load increased year by year . In Kuwait, large capacity thermal power plants have a large percentage in the total installed capacity of power plants, which makes the large capacity units with a basic load have to participate in the load regulation. The units have to deviate from the original design condition even run in the low load for a large time, which makes thermal efficiency of the unit decrease greatly among the factors that affect the thermal efficiency of the unit decrease greatly with time. Among the factor that affects the thermal efficiency of power plant, only the running modes and operating parameters can be adjusted by operating personal. Therefore the research of thermal power plants in the off design condition is of great signification in the selecting of running modes and operating parameters. Exergy destruction is measure of irreversibility that is the source of performance loss. Therefore an exergy analysis assessing the magnitude of exergy destruction identifies the location, the magnitude and source of thermodynamic inefficiencies in a thermal system. Recent developments in destruction concept have allowed the definition of a new performance criterion which offers some advantages over the tradition. Hence destruction analysis can improve resource utilization by determining inefficient, wasteful process with in thermodynamic systems and results obtained from such analysis can serve as a guide for reducing irreversibility and performance monitoring giving room for performance improvement.

2. Literature survey

In recent years , many practical and theoretical studies have been conducted on optimization of electric power plants sector carried to optimize process design from energy and exergy viewpoint , most of them included the effect of time –dependent exergy model was used to assess the destroyed that occur in the major components of 120MW steam turbine unit of Sapele power station , this study by Obodeh and Ugwuoke [1].As discussed in a brief over view of several thermo economic indicator suggested in the literature , the reason for this inability is the focus on specific exergy consumptions as independent variables of thermo economic model of energy system instead the real cause of the alteration of component behavior is the modification of its characteristic curve . Based on this concept, a new indicator measuring the alteration of the characteristic curve of the component affected by the operation anomaly is discoursed and applied to the combined cycle power plant of the TADEUS problem [2] some design parameters on the exergy loss or second law efficiency in both steam cycles [3] and combined cycles [4]. Beside some studied off design conditions for, example, Rashad and El Maihey [5] have done an exergy analysis of a power plant in Egypt with capacity of 315MW.Generally, design applications of exergy analysis aim to evaluate, compare, improve and optimize energy systems, but almost a great number of papers discussing second law of thermodynamics just deal with process optimization. As mentioned above, these efforts are useful in design phase of a unit, some studies presented an exergy analysis in an operating power station to find out the irreversibility and second law efficiency at aged units .As a power station particularly deals with high amount of energy, any changes of overall efficiency has high importance and should be carefully or degradation of components. In general aging is one of the most important reasons of efficiency reduction through the operation period, and many researchers focused on this. Despite many publications on the exergy analysis of power plant, most of them applied it to find optimum values for main cycle parame-

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ters. Sina and Hamid [6] have done an exergy of power plant in Iran with nominal capacity of 320 MW, in this study an exergy analysis of an operating unit was performed to clear main sources of exergy destruction to find out aging influence on the plant performance, out comes were compared with design results, this comparison cleared components which affected by aging and the amount of miss performance were specified too.

3. Material and method

It is apparent that exergy and derived indicators can be used profitably to evaluate effects of malfunctions. In fact, exergy depends on the thermodynamic variables mass, pressure and temperature, and as such, it is suitable to measure performance characteristics, which are effects of the operating conditions of the system. The irreversibility variations of components measure the effects of the malfunctions in terms of loss of potential work. Part of this loss is caused by a variation of component behavior while the remaining part is due to the propagation of induced effects through the productive chain. The data used for this study were base parameters for steam unit and measured values recorded in the station operation log book for the period of first start up to July 2015. The data collection were the pressures, temperatures and mass flow rate at various points in the analysis of the data, mean values of daily parameters were compared using statistical methods .This was followed by monthly average and then the yearly average for the period of the research. The average temperature ranges between 46 ° C in summer and 8° C Winter [7]. In this study, the mean ambient temperature 48 ° C was used, and pressure 1.013 bars. In analyzing the unit, the cycle was assumed to operate at study state with no lose heat transfer from any component to its surroundings and negligible kinetic and potential energy effects, such as boiler, stop valves, fuel and oil pumps, forced draft fans were neglected in the analysis. Pressure drops along pipelines were assumed to be negligible.

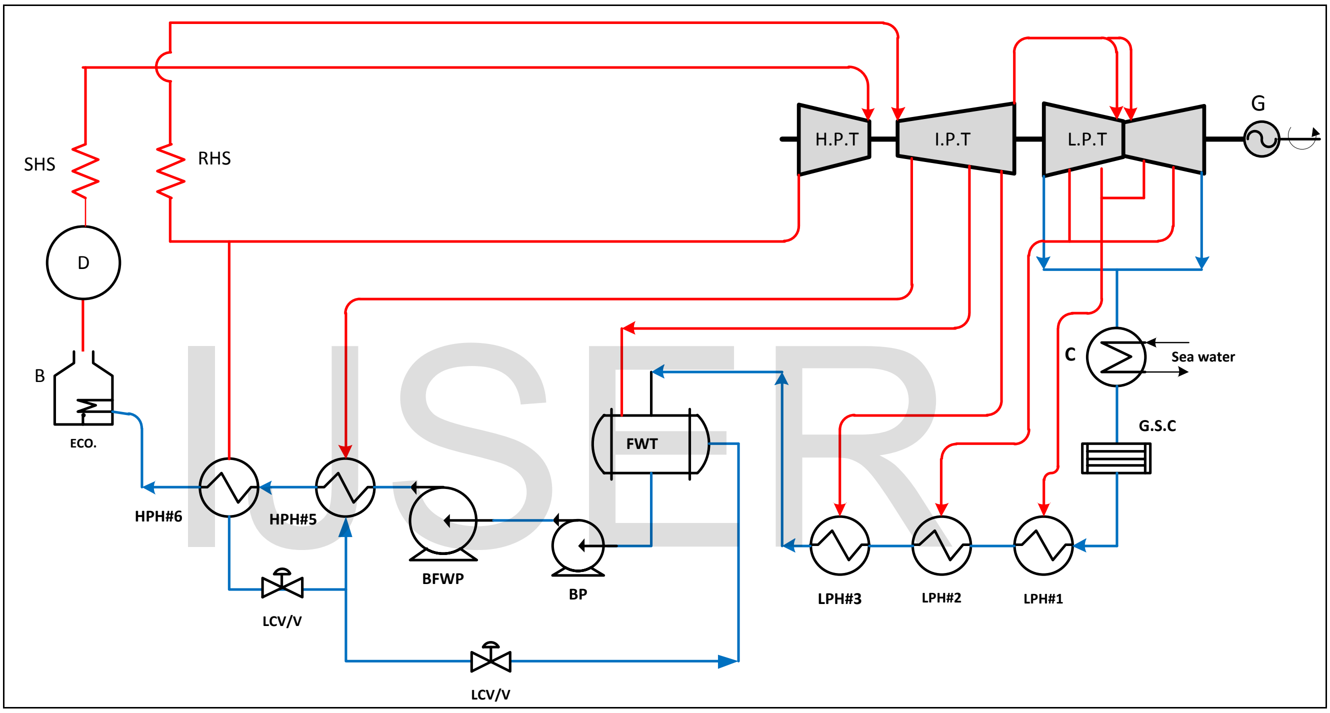
3.1 Power plant specification

This power plant was established at 1982 in Doha area it consists of 8 units each unit product 300 MW, this power plant is used natural gas, heavy oil and crude as fuel and sea water is used as cooling source. Doha west power station installed capacity and commissioning [7] in table 1. Flow diagram and power plant main components presented in figure 1, which illustrated steam unit major components and table 2 illustrated base technical data, summarized which were used study calculation.

Table 1 Doha west power station installed capacity and commissioning

Unit No.	Date of commissioning	Capacity
No.1	02/06/1983	300MW
No.2	25/06/1983	300MW

No.3	15/08/1983	300MW
No.4	31/08/1983	300MW
No.5	04/04/1984	300MW
No.6	26/04/1984	300MW
No.7	06/10/1984	300MW
No.8	02/12/1984	300MW



Figuer 1. Flow diagram thermodynamic cycle .

Figure 1 illustrated flow diagram thermodynamic cycle without details only abbreviations, each abbreviation shows a component in this figure showed in table 3.

Table 2 Techanical specification for DOHA west power station

Number of units	8
Unit installed capacity	300MW
Boiler steam out let pressure	146 bar
Boiler steam outlet temperature	540 °C

Boiler steam flow rate	1100 ton/hr.
Reheat steam pressure	38 bar
Reheat steam temperature	540 °C
Main fuel firing	Heavy oil , crude oil & Natural gas
Turbine type	Tandem – 2 cylinders – double flow exhaust
Number of HPT stages	10
Number of IPT stages	12
Number of LPT stages	6 double flow stages
Condenser pressure	70 mbar absolute
Extraction	6 turbine extractions
Feed water heaters	6 closed feed water heaters

3.2 Abbreviations

The abbreviations and acronyms the first time they are used in the text are illustrated in table 3.

Table 3 Definition Abbreviations

abbreviation	Definition abbreviation
HPT	: High Pressure Turbine
IPT	: Intermediate Pressure Turbine
LPT	: Low Pressure Turbine.
C	: Condenser.
GSC	: Gland steam condenser.
LPH	: Low pressure heater.
HPH	: High pressure heater.
FWT	: Feed water tank

ISSN 2229-5518

abbreviation	Definition abbreviation
BFWP/P	: Boiler feed water pump.
BP/P	: Booster pump.
ECO.	: Economizer.
D.	: Drum.
SHS	: Super-heat steam
RHS	: Reheat steam
LCV/V	:Level control valve
G	: Generator

3.3 Equations

For a control volume, an exergy balance equation is

$$\sum W^{\bullet} = \sum (1-\tfrac{T_o}{T})Q + \sum \Psi^{\bullet}_{in} - \sum \Psi^{\bullet}_{out} - \sum \Psi^{\bullet}_{loss} \quad (1)$$

Where ∑Ẇ=sum ideal work rate; ∑Q=sum hate supplied; To = surround

Turbine Exergy destruction rate

$$\Psi^{\bullet} = m^{\bullet}[h - h_o - T\,(s - s_o)] \quad (2)$$

Where $\Psi^{\bullet}$ is exergy rate. $m^{\bullet}_{st}$ Is steam flow rate with ton/hr.; h_i and h_e are enthalpy at inlet and outlet respectively; T is temperature and S is entropy.

$$\Psi^{\bullet}_{dest.} = \Psi^{\bullet}_{in.t} - \Psi^{\bullet}_{out.t} - w^{\bullet}_{t} \quad (3)$$

Where, $\Psi_{dest.}$ is exergy destruction rate with MW; $\Psi^{\bullet}_{in.t}$, $\Psi^{\bullet}_{out.t}$ are exergy at inlet and outlet turbine respectively; $w^{\bullet}_{t}$ is turbine work rate.

$$\eta_{ex.t} = 1 - \frac{\Psi^{\bullet}_{des.}}{\Psi^{\bullet}_{in.t} - \Psi^{\bullet}_{out.t}} \tag{4}$$

Where $\eta_{ex.t}$ is exergy efficiency.

Boiler feed water pumps exergy destruction rate :

$$\Psi^{\bullet}_{in,p} = m^{\bullet} C_p \left[(T_{in,w} - T_o) - T_o \ln(\tfrac{T_w}{T_o}) \right] \tag{5}$$

$$\Psi^{\bullet}_{e,p} = m^{\bullet} C_p \left[(T_{e,w} - T_o) - T_o \ln(\tfrac{T_{e,w}}{T_o}) \right] \tag{6}$$

$$W^{\bullet}_{P} = m^{\bullet}_{w} * \nu \left(p_{out,w} - p_{in,w} \right) \tag{7}$$

$$\Psi^{\bullet}_{des,p} = \Psi^{\bullet}_{in,p} - \Psi^{\bullet}_{out,p} + W^{\bullet}_{p} \tag{8}$$

$$\eta_{ex.p} = 1 - \frac{\Psi^{\bullet}_{des.p.}}{W^{\bullet}_{p}} \tag{9}$$

Where $\Psi^{\bullet}_{in,p}$ and $\Psi^{\bullet}_{e,p}$ are boiler feed water pump exergy rate at inlet and exit respectively ; $W^{\bullet}_{P}$ is pump work rate; $m^{\bullet}_{w}$ is boiler feed water flow rate, $\eta_{ex.p}$ is pump exergy efficiency.

Economizer exergy destruction rate:

$$\Psi^{\bullet}_{des.eco} = \Psi^{\bullet}_{in.eco} - \Psi^{\bullet}_{out.eco} \tag{10}$$

$$\eta_{ex.eco.} = \frac{\Psi^{\bullet}_{out.eco.}}{\Psi^{\bullet}_{in.eco}}$$

(11)

Evaporator exergy destruction rate:

$$\Psi^{\bullet}_{des.evp.} = \Psi^{\bullet}_{in.evp.} - \Psi^{\bullet}_{out.evp.} \tag{12}$$

$$\eta_{ex.evp.} = \frac{\Psi^{\bullet}_{out.evp.}}{\Psi^{\bullet}_{in.evp}} \quad (13)$$

Where; $\Psi^{\bullet}_{des.evp.}$ =Evaporator exergy destruction rate, $\Psi^{\bullet}_{in.evp.}$ and $\Psi^{\bullet}_{out.evp.}$ are evaporator exergy rate at inlet and exit respectively, $\eta_{ex.evp.}$ is evaporator exergy efficiency.

Super heater exergy destruction rate:

$$\Psi^{\bullet}_{des.SH.} = \Psi^{\bullet}_{in.SH.} - \Psi^{\bullet}_{out.SH.} \quad (14)$$

$$\eta_{ex.SH.} = \frac{\Psi^{\bullet}_{out.SH.}}{\Psi^{\bullet}_{in.SH.}} \quad (15)$$

Reheater exergy destruction rate:

$$\Psi^{\bullet}_{des.RH.} = \Psi^{\bullet}_{in.RH.} - \Psi^{\bullet}_{out.RH.} \quad (16)$$

$$\eta_{ex.RH.} = 1 - \frac{\Psi^{\bullet}_{dest.RH.}}{\Psi^{\bullet}_{in.RH}} \quad (17)$$

Condenser exergy destruction rate:

$$\Psi^{\bullet}_{des.C.} = \Psi^{\bullet}_{in.C.} - \Psi^{\bullet}_{out.C.} \quad (18)$$

$$\eta_{ex.C.} = \frac{\Psi^{\bullet}_{out.C.}}{\Psi^{\bullet}_{in.C.}} \quad (19)$$

4. Results and discussion

Using the data obtained from Doha west power station design and operation log book and exergy relations and second low efficiency equations from 1 to 19 for each unit steam power station components. After more than 30 years of age the passage of the steam power station and 180000 to 210000 running hours were originally designed the plants were expected to run at bas load. The only thermal limit applied in design was creep thermal fatigue resulting from frequent stops/stars was not anticipated. Due to detrition steam power units of more than 210000 running hours are facing serious threats in view of their remaining life time .Even with proper operation and maintenance, the flow path section in the steam turbine plant will become fouled eroded, corroded and covered with results scale. The consequence is increased exergy destruction in their various components. The base values of exergy destruction and exergy efficiency in units of steam power station at variable loads at 50%, 75% and 100% of maximum load.

4.1 At 50% of maxumm load

At load 50% of maximum load, the exergy destruction rate in boiler feed water pump is 0.01 MW /year and Percentage of destruction is 3.25%. The exergy destruction rate in economizer is 0.08MW/year, and the percentage of destruction is 4.17%. In evaporator, the destruction rate is 0.87MW and 10.46%. In super heater is 0.57MW/year and 4.17%. In reheater is 0.97MW and6.71%.In HP turbine is 0.26MW/year and 5.55%. In IP turbine is 0.41MW/year, and 2.6%. In LP turbine is

Table 3. Steam units running hours and generating of electrical energy at Doha west power station during 2013 [7]

	Unit#1		Unit#2		Unit#3		Unit#4		Unit#5		Unit#6		Unit#7		Unit#8	
Month	Running hours	Total generator (mMw/hr)	Running hours	Total generator (mMw/hr)	Running hours	Total generator (mMw/hr)	Running hours	Total generator (mMw/hr)	Running hours	Total generator (mMw/hr)	Running hours	Total generator (mMw/hr)	Running hours	Total generator (mMw/hr)	Running hours	Total generator (mMw/hr)
January-13	0.00	0	0.00	0	0.00	0	0.00	0	740.45	135555	374.00	68855	610.15	111735	740.00	137255
February-13	0	0	0.00	0.00	0.00	0	0.00	0	672.00	1172270	134.45	26275	534.00	90625	322.15	58235
March-13	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.00	40.00	8215	744.00	149905	0.00	0
April-13	0	0	0.00	0.00	0.00	0	0.00		731.00	146575	217.15	49165	20.15	4115	0.00	0
May-13	28.47	262	41.29	472	21.21	327	16.38	238	720.00	157975	418.45	87300	299.15	64120	418.00	87550
June-13	0	0	0.00	0.00	0.00	0	1.14	13	744.00	159265	720.00	156245	720.00	156505	720.00	1556385
July-13	0.00	0	0.00	0	0.00	0	0.00	0	720.00	155106	744.00	156520	711.4	139710	740.00	155905
August-13	0	0	0.00	0.00	0.00	0	0.00	0	641.00	136475	744.00	146665	720.00	140935	744.00	146560
September-13	0.00	0	1.00	12	1.05	10	1.10	13	744.00	145510	720.00	141120	744.00	145095	720.00	141090
October-13	0	0	0.00	0.00	0.00	0	0.00	0	720.00	139770	744.00	145165	720.00	144755	744.00	145206
November-13	0.00	0	2.02	9	0.00	0	0.00	0	146.15	3048	720.00	144405	744.00	143285	720.00	145030
December-13	0	0	1.32	8.00	0.00	0	0.00	0	0.00	0	623.45	120000	744.00	143085	740.00	143255
Total	28.47	262	45.63	501	22.26	337	18.62	264	6578.60	2351549	6199.5	1249930	7310.85	1433870	6608.15	2716471

0.38MW/year and 2.98%. In HP heaters are 0.18MW/year and 4.10% and in LP heaters are 0.2MW/year, and 3.77%.

Table4 Exergy desruction rate and percentage destruction.

Component	Exergy Losses (MW) at 150 MW			
	Design	Ageing	deff.	destroyed %
Boiler feed pump	0.28	0.56	0.01	3.25%
Economizer	1.98	4.45	0.08	4.17%
Evaporator	8.22	34.46	0.87	10.64%
superheater	13.72	30.88	0.57	4.17%
Reheater	13.72	41.34	0.92	6.71%
H.P Turbine	4.67	12.46	0.26	5.55%
I.P Turbine	15.79	28.12	0.41	2.60%
L.P.Turbine	12.73	24.12	0.38	2.98%
HP heaters	4.44	9.90	0.18	4.10%
LP heaters	5.28	11.25	0.20	3.77%

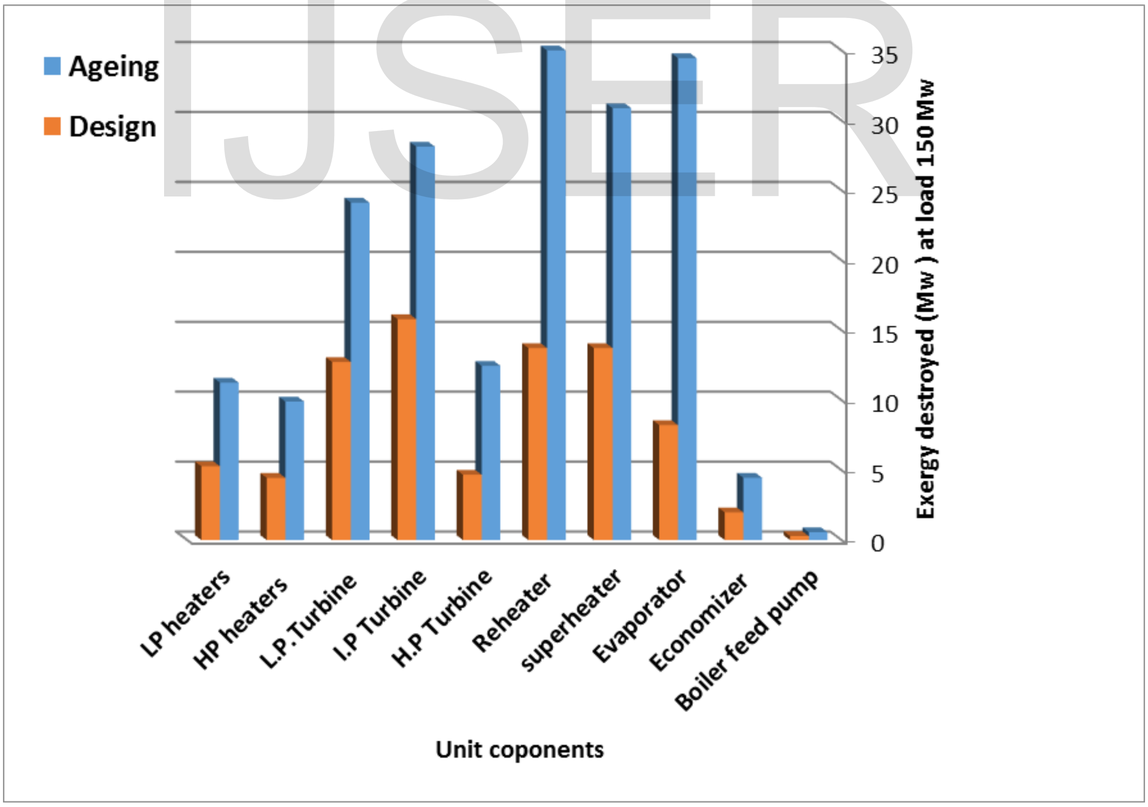


Figure 2 Compare between design exergy destruction and aging at load 50% .

4.2 At 75% of maxumm load

At load 75% of maximum load, the maximum exergy destruction rate was found evaporator, the destruction rate is 0.79MW /year and Percentage of destruction is 11.92% while the minimum destruction rate was fund in HP turbine is 0.14MW/year and 1.35% , also the exergy destruction rate in economizer is 0.11MW/year, and the percentage of destruction is 5.59%. In Boiler feed water pump, the destruction rate is 0.01MW/year and 3.61%. In super heater, the destruction rate is 0.58MW/year and 8.23%. In reheater is 0.19MW/year and 6.71%.In IP turbine is 0.36MW/year and 2.86% . In LP turbine the destruction rate is 0.45MW/year, and 3.4%. In HP heaters the destruction rate is 0.16MW/year and 2.76% and in LP heaters , the destruction rate is 0.14MW/year and 4.95% .

Table5 . Destruction rate at 75% of maxumu load during period 1983-2014

components	Design	Ageing	deff.	destroyed %
Boiler feed pump	0.31	0.64	0.01	3.61%
Economizer	1.92	5.15	0.11	5.59%
Evaporator	6.63	30.34	0.79	11.92%
superheater	7	24.29	0.58	8.23%
Reheater	7	12.8	0.19	2.76%
H.P Turbine	10.75	15.10	0.14	1.35%
I.P Turbine	12.75	23.68	0.36	2.86%
L.P.Turbine	13.03	26.57	0.45	3.47%
HP heaters	5.62	10.28	0.16	2.76%
LP heaters	2.85	7.08	0.14	4.95%

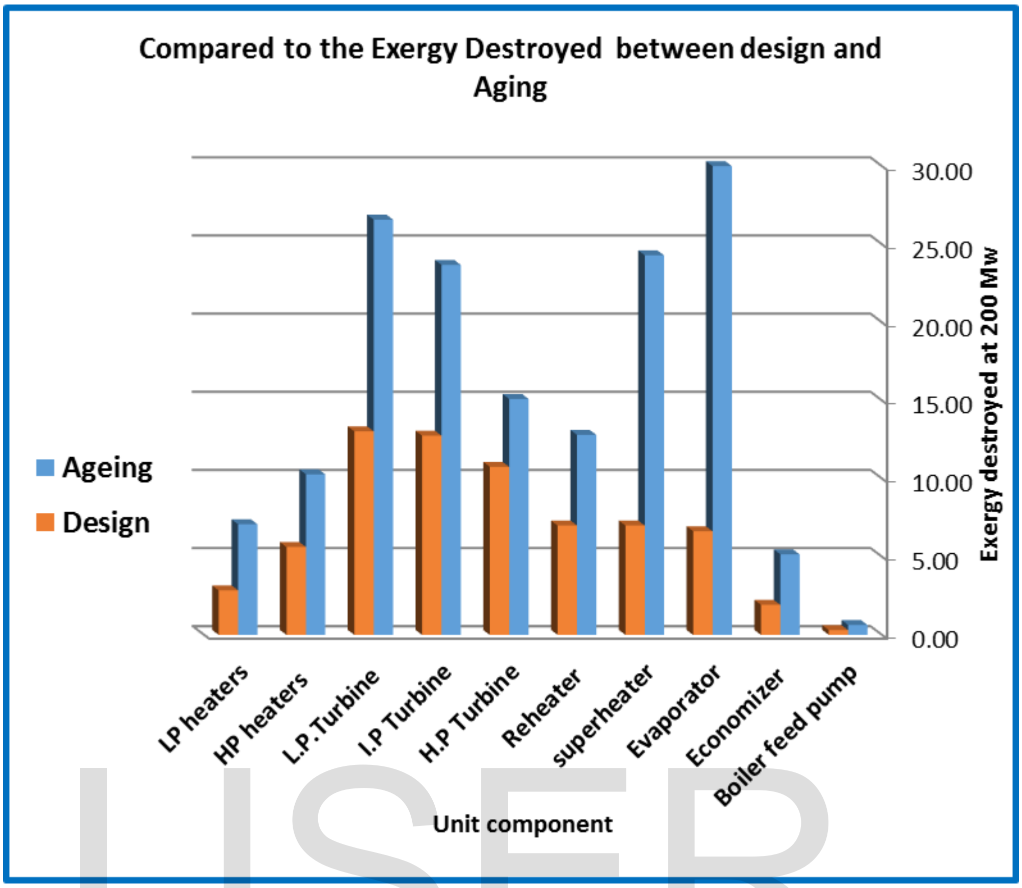


Figure 1 compare destruction rate between design and aging .

4.3 At 100% of maxumm load

At load 100% of maximum load, the maximum destruction rate was fund in evaporator, the destruction rate is 0.79MW/year and 11.81%. and minimum destruction rate was fund in super heater is 0.57MW and 4.17%. boiler feed water pump is 0.01 MW /year and Percentage of destruction is 3.25%. The exergy destruction rate in economizer is 0.08MW/year, and the percentage of destruction is 4.17%. in reheater is 0.97MW and6.71%.In HP turbine is 0.26MW/year and 5.55% . In IP turbine is 0.41MW/year, and 2.6%. In LP turbine the destruction rate is 0.08MW and 5.52%.

Component	Exergy Losses (MW) at 300 MW			
	Design	Ageing	Deff.	destroyed%
Boiler feed pump	0.51	1.15	0.02	4.17%
Economizer	3.58	6.45	0.10	2.68%
Evaporator	6.68	30.34	0.79	11.81%

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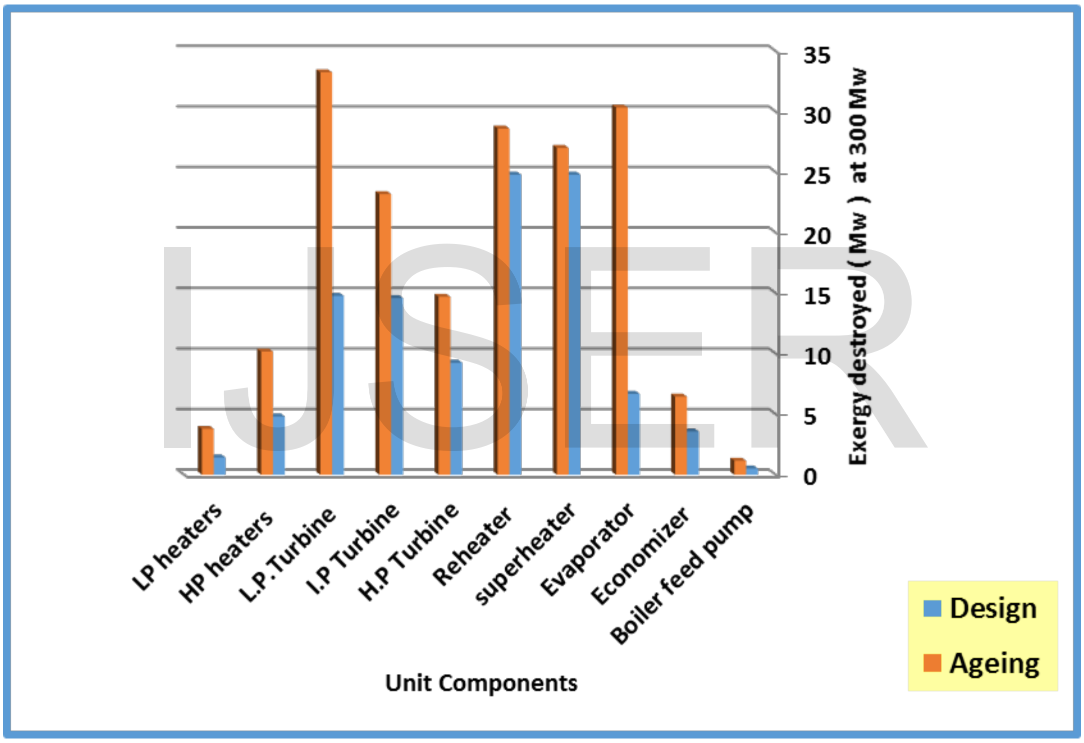
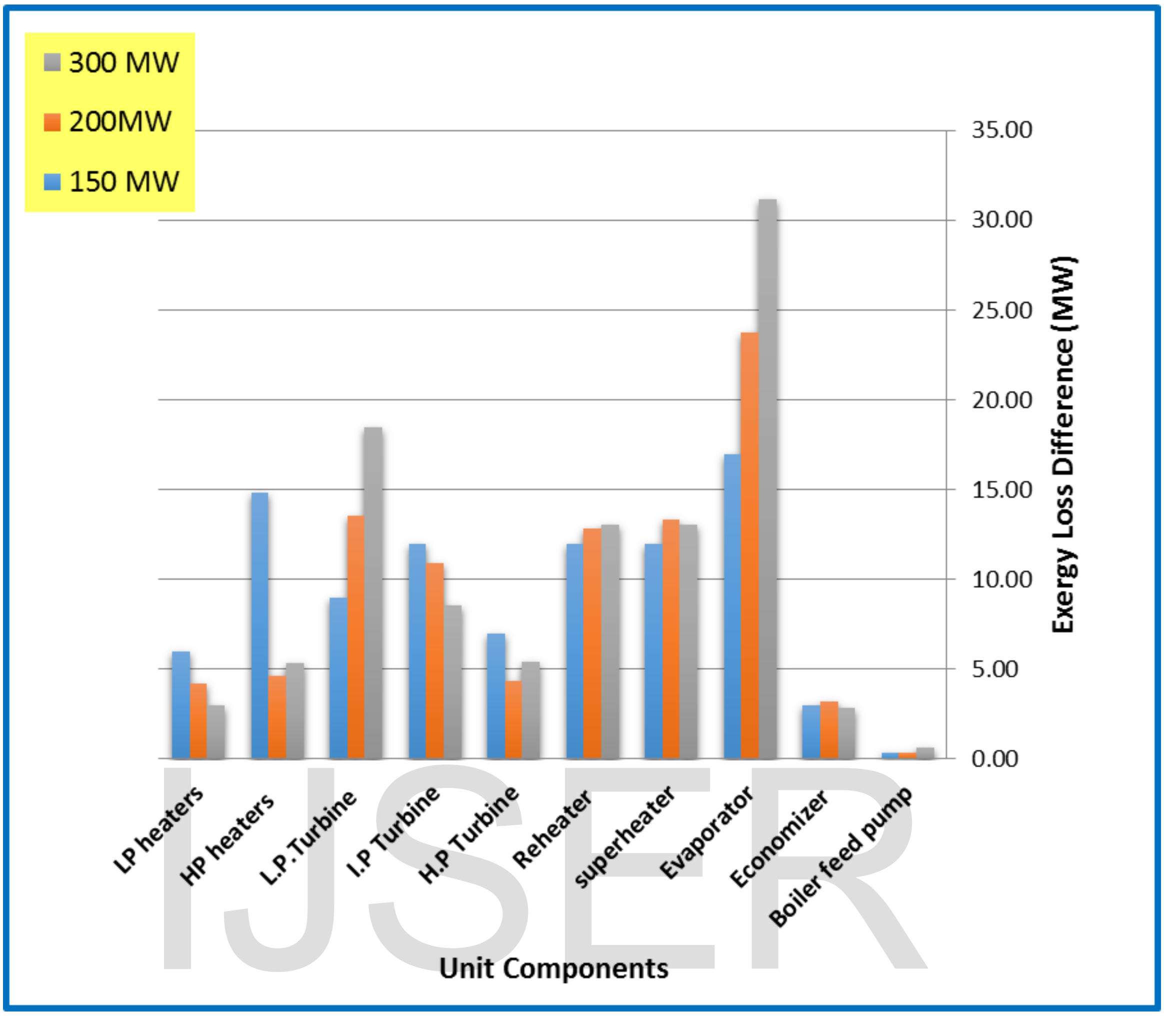
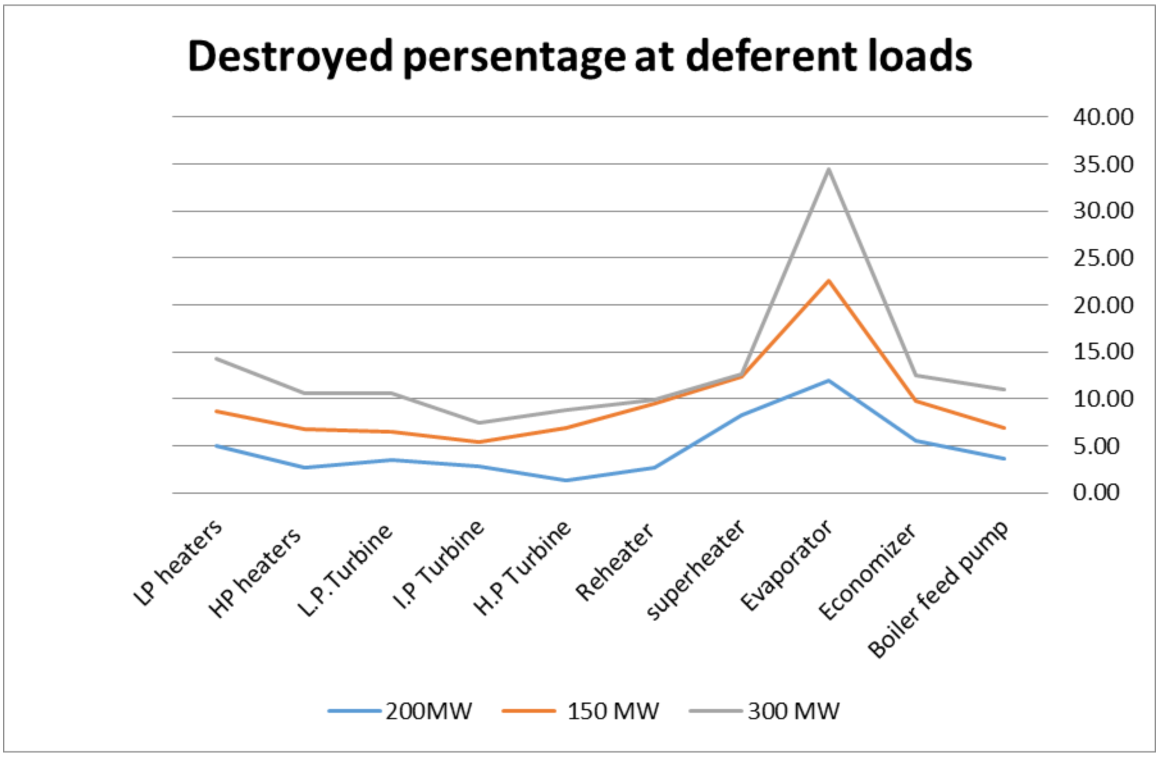
superheater	24.79	27.00	0.07	0.30%
Reheater	24.79	28.6	0.13	0.51%
H.P Turbine	9.26	14.70	0.18	1.96%
I.P Turbine	14.60	23.19	0.29	1.96%
L.P.Turbine	14.78	33.25	0.62	4.17%
HP heaters	4.82	10.18	0.18	3.70%
LP heaters	1.43	3.79	0.08	5.52%




300 MW
200MW
150 MW
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Exergy Loss Difference (MW)
LP heaters
HP heaters
L.P.Turbine
I.P Turbine
H.P Turbine
Reheater
superheater
Evaporator
Economizer
Boiler feed pump
Unit Components


Destroyed persentage at deferent loads
40.00
35.00
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0.00
LP heaters
HP heaters
L.P.Turbine
I.P Turbine
H.P Turbine
Reheater
superheater
Evaporator
Economizer
Boiler feed pump
200MW
150 MW
300 MW

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