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Impact of Boiler Modifications on the Process System Value of a Captive Power Plant

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Abstract:*The economic performance of power plants has received significant notice in today's modern world. An important parameter that remains as the key performance indicator of power plants of modern times is the plant availability. The impact of modifications on the process system value of power plants is a significant measure that will predict much earlier the realistic economic performance that would have realised if they are running after modification implementations.The paper presents the impact of the modifications done in De-Super heaterand Flame Burner System of a Boiler in its conversion from Oil fired to LNG fired system on the process system value of a 7MW Captive power plant of a fertilizer process industry.The paper also examines the criticality of LNG price variation on the modified processes.*

Keywords:*Availability, Captive Power Plant ,Impact ,Process System Value, Reliability.*

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I. Introduction

With more and more emphasis given for energy conservation programs and policies, most existing systems are being modified or redesigned with an objective of improving energy efficiency [1].Plant availability is a critical driver for the economic performance of a plant [2]. While designing the systems, often the focus is on immediate demands of the equipment, and the broader issue of how the system parameters affect the equipment is overlooked. It is important to recognizethat process efficiency and reliability are equally important[3].

The recent modifications done during the process of fully changeover of the fuel feed stock from Furnace Oil to Regasified -LNG of the captive power plant of a major petrochemical and fertilizer industry and the opportunity to assess the impact of the modification on the process system value of the plant through the process system evaluation model incorporating reliability and availability was noticed. The industry was a major giant in the petrochemical sector but it is cash strapped over a few years due to various reasons and the feedstock changeover is a major step in the revival process to gain momentum in the economic performance of the plant. During the surveillance visit it is observed that an assessment of the reliability and availability of major power plant components have not been done in the context of modifications before and after modifications. The objective of this paper is to present a process system value model by incorporating reliability and availability and its application on the mentioned fertilizer process industry. The models determine the process system value before and after modifications, change in process system value due to modification and also determine the pay back period of the investment for modification.The value of the system can be defined by considering the present worth of expected future cash flows.

Reliability and availability are the basic concepts employed in the development of the process system value model in this paper. The model is developed through a transition of actual configuration of power plant into Reliability Block Diagrams that help in calculating the system reliability and availability.The reliability incorporated process system modeldetermine the profitability of the process modifications technically and commercially.

II. Reliability and Availability

Reliability can be defined as the probability that an item can perform a required function for a specified period of time under the specified operating conditions [4-5]. Reliability of an individual component in terms of failure rate can be expressed as:

$R(t) = e^{-{}_0\int^{t} Z(t)\,dt}$(1)

For a component with a constant failure rate, Eq. (1) reduces to

$R(t) = e^{-\lambda t}$(2)

Equation (2) is generally used for the calculation of component reliabilities for a given system. In reality, even though this holds good only in-between the period of infant mortality and wear-out, it is often a reasonably good assumption as this time frame is equal to almost the entire lifetime of any equipment. The constant failure rate model is widely used in the literature to reduce the computational burden of the resulting problem because the parameter MTBF which can be obtained from Equation (3) becomes time-independent in this case [3].

$MTBF = {}_0\int^{\alpha} R(t)dt = {}_0\int^{\alpha} e^{-\lambda t} = 1/\lambda$ (3)

Similarly, MTTR, which is the average time taken to repair a failed component, can be expressed as

$MTTR = 1/\mu$ (4)

Availability can be defined as the probability that an item will be available when required, or as the proportion of total time the item will be available for use [5]. The proportion of total time that the item is available is the steady state availability. Availability is determined by the reliability and maintainability of an item. For a simple unit with a constant failure rate and a constant mean repair rate, the steady state availability can be expressed as

$A_i = \mu / (\lambda + \mu)$ (5)

Typical approaches to achieve high system reliability are:
(1) increasing the reliability of system components and
(2) using redundant components in various subsystems in the system [7–9]. The modification of an existing system with a view to improve energy efficiency should consider these factors. The change in system configuration resulting from system modification can adversely affect the system reliability. In order to determine the economic feasibility of the new proposal several methods have been suggested to perform analyses of energy conversion systems and supply information from different view points. In the area of energy investigations,especially worth mentioning are the life cycle assessment (LCA) method presented by Valero [10], its exergetic version ExLCA proposed by Cornelissen et al. [11] and the thermo economic theory presented by Lazzaretto et al. [12], Lozano and Valero [13] and Tsatsaronis and Winhold [14].This was further extended to include environmental implications by Badino and Baldo[15]. Cumulative exergy cost accounting (CExC) was proposed by Szargut[16], extended exergy accounting (EEA) by Sciubba[17], environomic theory by Von Spakovsky and Frangopoulos [18] and emergy accounting by Odum[19].

Researchers at Lawrence Berkeley National Laboratory have used life cycle costing in the United States Department of Energy's rulemaking for residential central air conditioners [20]. The life cycle cost consists of two main components: (1) the first cost of buying and installing equipment and (2) the operating costs summed over the lifetime of the equipment, discounted to the present.

$$\text{Life – cycle cost} = \text{Installation cost} + \frac{\sum_{n=1}^{\text{Life time}} \text{Operating Cost}}{(1+i)^n} \quad (6)$$

The approach involves comparing the total life cycle cost (LCC) of owning and operating a more efficient appliance with the LCC for a baseline design. Lutz et al. [21] presented the method used to conduct the LCC analysis and also presented the estimated change in LCC associated with more energy efficient equipment. The LCC calculated in this analysis expresses the costs of installing and operating a furnace or boiler for its lifetime starting in the year 2012 – the year a new standard took effect. The analysis also calculated the payback period for energy efficiency design options. The pay back period represents the number of years of operation required to pay for the increased efficiency features. It is the change in purchaseexpense due to an increased efficiency standard divided by the change in annual operating cost that results from the increased efficiency. The payback period equation is expressed as

$$\text{Payback option} = \frac{\text{Equipment Cost}_{\text{Option}} - \text{Equipment Cost}_{\text{Base}}}{\text{Equipment Cost}_{\text{Option}} - \text{Equipment Cost}_{\text{Base}}} \quad (7)$$

where base is the base case design and option is the design option being considered.

It is evident from the above discussions that the system valuation and pay back analysis hardly take the reliability and availability aspects into consideration. That is, it happens that, while determining the economic feasibility of the new option, reliability aspects (or loss due to unavailability) are not taken into consideration.

III. Process system value model

The value of the system can be by considering the present worth of expected future cash flows. The model takes into consideration the system availability, in addition to the other cost elements like investment cost, and maintenance as well as operating cost[2]. Thecash flow model for system valuation is shown in Fig. 1. The model is based on the following assumptions:

- Process components are assumed to have a constant failurerate as well as a constant repair rate;
- Availability under consideration is steady state availability;
- Interest rate is constant throughout;
- Depreciation of the plant is not considered

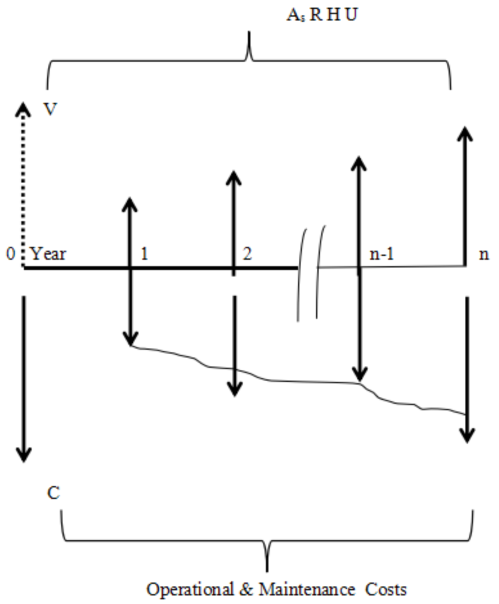


Fig -1 :*Process System Value Evaluation Model*

With reference to the cash flow model shown in Fig. 1, the process system value can be expressed as:

$$V = As\ R\ H\ U\ (P/A,i,n) - C - As\ Os \frac{[\ [1-(i+k)^{n}\ (1+i)^{-n}\ ]}{(i-k)} \quad (8)$$

The valuation Equation (7) can be used only for cases where i≠k and when i = k the equation will get modified as:

$$V = As\ R\ H\ U\ (P/A,i,n) - C - \left(\frac{nAsOs}{(i-k)} \right) \quad (9)$$

The quantity (P/A, i, n) in the Equation (8) is the uniform series present worth factor [21] and can be obtained as:

$$(P/A,i,n) = \frac{[(1+i)^{n}-1\ ]}{i(1+i)^{n}} \quad (10)$$

Whenever a process system is to be modified for energy savings, it is important to know the expected change in system value. In this case, the investment for modification, expected annual savings due to modification as well as the change in system availability has to be taken into consideration. Change in process availability results from the change in system configuration. The change in process value can be expressed as:

$$V_C = [A_M(RHU - O_M)\text{-}A_S(RHU - O_S)]\ (P/A,i,n) - C_m \qquad (11)$$

The payback period corresponds to the value of n that makes $V_C = 0$.

IV. System Description and Modification

The recent modifications implemented on a 7 MW Captive Power Plant of a major fertiliser industry is evaluated for assessing impact on process system value of the plant on account of modification in Boiler burner management system and De-Super heater in the conversion of a fuel oil fired Boiler to Re Gasified – LNG fired boiler. The power plant consists of three boilers each of capacity 60TPH .Furnace oil is the fuel currently used in the system .For improving energy efficiency the system is modified to dual function mode where the power plant can be operated on Furnace oil as well as Re-Gasified LNG as per availability of the fuel.

Refer Fig 2 for existing arrangement of burner system and Fig.3 forexisting lay out of captive power plant .

Refer Fig 4 for the modified arrangement of burner system and Fig.5 for modified lay out of captive power plant.

The features of existing arrangement of power plant are as below. .

Threeboilers of 60TPH capacity.

- Bi-drum arrangement with bank tubes
- Furnace is made of membrane wall arrangement and 3 sets of superheaters viz. LTSH,Platen SH and FSH and economizer is arranged in the intermediate and bank pass of boiler.
- Boiler is provided with front wall firing with FD system and FD fan is supplying required draft.
- Type of air pre heater is tubular air heater type.
- There is a common chimney for all the three boilers.
- Steam Coil Air Pre Heater and Air Pre Heater are provided
- Boiler fitted with 2 burners arranged in one row in the boiler front wall and connected to a common windbox arrangement for the airsupply to the boiler .
- Boiler 1 and 2 – Fire off gas and furnace oil /LSHS
- Boiler 3 – only Furnace oil /LSHS

Boiler Parameters are

- Main Steam flow : 60 TPH
- Main Steam pressure : 110 kg /sq.cm
- Main Steam Temp : 520 Deg Celsius
- Boiler Feed water temp : 183 Deg C

Details of Boiler and burner fittings:

Equipments and Parameters

- No: of boilers -3 @ 60TPH
- Furnace Width : 4877 mm
- Furnace Depth : 6401 mm
- Draft type : FD

Refer Table -1 for Burner data. The relevant parameters are Fuel used, Fuel combination ,Number of burners per boiler , Register size , Atomisation,Atomizing pressure, T/d, Maximum,minimum and normal oil capacity per burner, Oil pressure at burner max. and the type of gas.

Table-1 – BURNER DATA

Burners	Units 1 and 2	Unit 3
Fuel	LSHS/FO&Off gas	LSHS/FO
Fuel combination	Oil+off gas (off gas to be fired only if oil flow to burner is > 250 kg/hr	Only oil firing provision provided
No: of burners per boiler	2(located in front wall)	2(located in front wall)
Register size	720 mm	665 mm
Atomisation	Steam	Steam
Atomising pressure	7 kg per sq.cm	7 kg per sq. Cm
T/d	01:04	01:04
Max. Oil capacity/burner	2530 kg/hr	2530 kg/hr
Normal oil capacity/burner	2300 kg/hr	2300 kg/hr
Minimum oil capacity/burner	632 kg/hr	2(located in front wall)
Oil pressure at burner max.	14.5 kg/sq.cm	14.5 kg/sq.cm
Type of gas	Fuel gas(off gas from fertiliser plant)	N/a

The fuel used in the existing arrangement is Fuel oil and Off gas where as in the modified arrangement the fuel used is LNG.

Refer Table - 2 for Specification of fuel oil (furnace oil). The parameter in the table are the Type of fuel oil/ sg, Gross Heating Value, Viscosity of fuel required at burners, Oil flow amd pressure per burner at peak load and m.c.r respectively.

Table 2 : Specification of fuel oil

Type/sg	Kg/hr	Heavy fuel oil/1.008
Gross heating value	Kcal/kg	9500
Viscosity required at burners	15-20 degcelsius	4
Oil flow per burner at peak load	Kg/hr	2530
Oil flow per burner at m.c.r	Kg/hr	2300
Oil pressure at burner for peak load	Kg/sq.cm	14.5
Oil pressure required at burner for m.c.r	Kg/sq.cm	13.5

The off gas data ia as per Table-3.The given data is analysis by weightfor the content of gases Hydrogen,Methane,Oxygen, and Nitrogen..

Table 3: Specification for off-gas

.Analysis by weight		
Hydrogen	Kg/hr	92
Methane	Kg/hr	51
Oxygen	Kg/hr	4
Nitrogen	Kg/hr	2315
Fuel gas qty	Kg/hr	2662

Refer Table 4 for Properties of off gas.The properties mentioned are Calorific Value, Density,Gas pressure and Temperature.

Table 4: Properties of off gas

Calorific value	K cal/kg	3000
Density at 15 deg. celsius	Kg/ m^3	0.696
Gas pressure at terminal	Kg/sq.cm	10 @ 38 degree celsius
Temp	Degree celsius	38 degree celsius

Refer Table 5 for LNG specification.The parameters that are specified are Expected pressure and temperature of LNG, Gas calorific value, Molecular weight and Specific density.

TABLE-5: LNG specification

Expected pressure and temperature of lng	Kg/hr	85 bar , 0 degree celsius
Gcv	Kcal/kg	114800
Mol.weight		18.29
Specific density		0.65

Refer Table 6 for Required parameters at Boiler terminal point. The required parameters are Pressure of Re gasified LNG , Temperature and Dryness.

Table 6: Required parameters at boiler terminal point

Pressure of re-gasified LNG	Kg/sq.cm	4(min 3 –max 5 kg /sq.cm
Temperature	Deg. Celsius	Ambient temp .approx. 30 deg Celsius
Dryness	%	100

The Captive Power Plant Reliability Data for 8000 hours were taken from the power plant before and after the modification.Collected data MTBF and MTTR are is given in Table 7.After implementation , improvement inMBTF and MTTR are observed in Boiler , and Piping and new values are accounted for LNG Burner System as given in Table-8.

Table7 :CPP Components MTBF and MTTR Data before Modification

Sl no.	CPP components	MTBF(hrs)	MTTR(hrs)
1	FWP1	7500	4
2	FWP2	7000	4
3	FWP3	7800	4
4	Boiler	3000	8
5	Steam header	4400	3
6	Steam turbine	4400	48
7	Condenser	5000	8
8	Cond. Pump 1	3000	4
9	Cond. Pump 2	3000	4
10	Strainer 1	2000	3
11	Strainer 2	2000	3
12	Strainer 3	2000	3
13	Fuel pump 1	4000	4
14	Fuel pump 2	4000	4
15	Fuel pump 3	4000	4
16	Fuel pump 4	4000	4
17	Fuel pump 5	4000	4
18	Fuel pump 6	4000	4
19	Heat exchanger	3000	8
20	FD fan	4400	16
21	SCAPH	3000	14
22	APH	3000	14
23	FSH	5000	48
24	DSH	5500	48
25	PSH	8500	48
26	LTSH	6000	48
27	Economiser	5000	48
28	Start up boiler	4000	24
29	LPG-FO-Atm .Steam Burner System	3000	6
30	Chilled water system	3700	5
31	Piping	5000	4

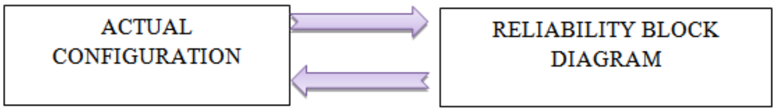
Refer Table 7 for the "Mean time between failure" (MTBF) and "Mean time to repair" (MTTR) for the components of Captive power plant listed in table.

Table 8 :CPP components with improved reliability data after modification

SlNo.	CPP components	MTBF(hrs)	MTTR(hrs)
1	Boiler	5000	8
2	LNG burner system	7000	3
3	Piping	7000	4

Refer Table 8 for the improved reliability data after modification for the CPP components .Those components are Boiler, LNG Burner system and Piping.

The model is developed through a transition of actual configuration into Reliability Block Diagrams.



The actual configuration before modification is given Fig 4 .The actual configuration after modification is given in Fig -5 .The reliability block diagrams are built and shown in Fig -6and Fig-7 for before and after modification status respectively.

V. Existing System of Flame Burner& De-Super heater of Boiler

The existing arrangementofburner have lines of furnace oil supply , 14 Kg/Sq. cm steam ,Purge Gas and LPG.Furnace oil supply the main heat energy input to the boiler whereas the use of purge gas is as a process bye product utilization .LPG supply is for ignition of burner and ignition is sparked by an electricigniter .For full load conditions ,ie for a steam production rate of 60TPH , the furnace oil supply rate is 4185 kg/hr. .The thermal efficiency of boiler is found to be 67.58 %.The cost of furnace oil is INR 32,000 per Metric Tonne. The furnace oil is used in running the captive power plant of the industry where as the main objective of the plant is steam generation for the production of ammonia which is used for manufacturing fertilizer-the prime product of the industry.. The power output from the Captive power plant is 7MW electric power .The raw material for manufacturing Ammonia is mainly Naphtha which is a bye product after dry distillation of petroleum products .The scope of modification in the power plant is for LNG conversion of the plant on account of the substitution of Naphtha with cheaply available(at project initiation phase time period) Regasified LNG .The cost of RLNG at the project initiation time is USD 14.5 per MMBTU.The proposed plan to use RLNG for production of ammonia has resulted in the decision to use the RLNG in captive power plant replacing furnace oil. Refer Fig:2 for the existing arrangement of the burner system.

There are several advantages on account of LNG Conversion.

LNG is cheaply available than furnace oil and hence the fuel cost is low (however scenario changed in due course of time and the condition is dealt in later Section). The heating value of LNG is more than the furnace oil. The boiler maintenance due to of carbon deposit in oil gun, soot formation etc. is eliminated.The requirement of a small capacity start up boiler can be eliminated where the steam from the start up boiler was used to pre- heat the fuel oil and also to generate the atomizing steam.Atomizing steam at 7 kg/cm^2 is used to atomize furnace oil at the oil gun point to facilitate the smooth firing..Operational and maintenance cost is low due to reduced pipe line accessories and elimination of startup boiler.The reliability and availability of the captive power plant increases

The existing outer dimension of De-Super heater is 1inch and the existing material grade is of low grade as it is causing De –Super heat pipe sagging.

Refer Fig-2 for the existing arrangement of burner system. Refer Fig-3 for the existing lay out of the Captive Power Plant.

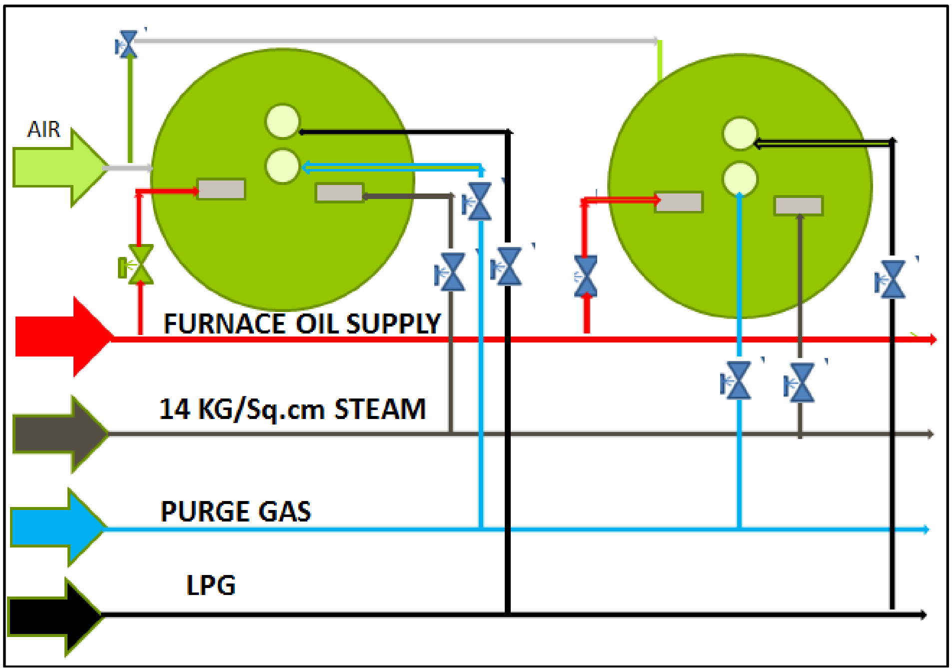


Fig 2: Existing Arrangement of Burner System

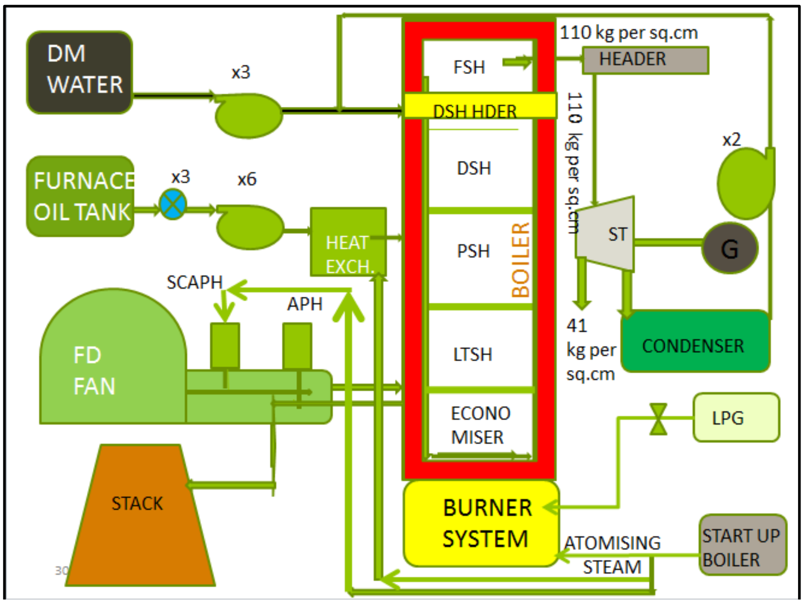


Fig 3 : Existing layout of Captive Power Plant

VI. Modified System of Flame Burner & De-Super heater of Boiler

The modified arrangement of burner have lines of furnace oil supply,14 Kg/Sq. cm steam ,Purge Gas , LPG and LNG .The new arrangement has a dual function mode.When supply of LNG is not available the plant can be run with furnace oil.The plant running data of one year is collected from the power plant .The total hours of operation per year is 8000 hrs .Table -7 show the components .The existing lay out is with a smaller header diameter De-Super Header line and using only Furnace oil based burner management system.The modified layout of captive power plant have increased diameter of De-Super Heater pipe and modified flame burner system with additional LNG line .The output parameters of the power plant is not changing due to the modification .The rated power of CPP 7MW ,the steam load 60 TPH , Pressure 110 bar and Temperature 520 Deg. Celsius are the same after and before modification .The LNG conversion modification is expected to yield production of more steam at high pressure, hence the De-Super heater diameter increased from 1 inch to 2 inches in order to maintain the initial thermodynamic state parameters .The material grade of De-Super heater pipeline is upgraded to overcome sagging. There are about 31 power plant components/sub systems identified and their MTBF and MTTR are collected from the power plant. The reliability and availability are calculated for these thirty one components /subsystems. There are three subsystems that undergo a change in reliability and availability values due to the modification. They are boiler and piping and burner system . LNG Burner system is a new addition hence its fresh reliability and availability values are calculated.

Refer Fig-4 for the modified arrangement of burner system . Refer Fig -5 for the modified lay out of the captive power plant..

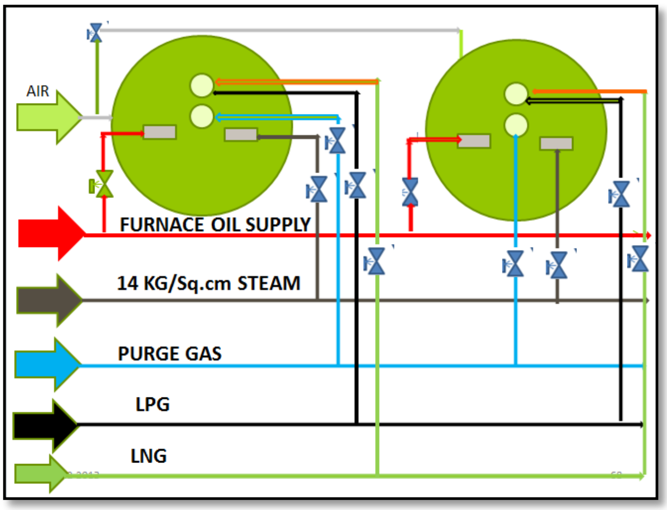


Fig 4: Modified Arrangement of Burner Syste

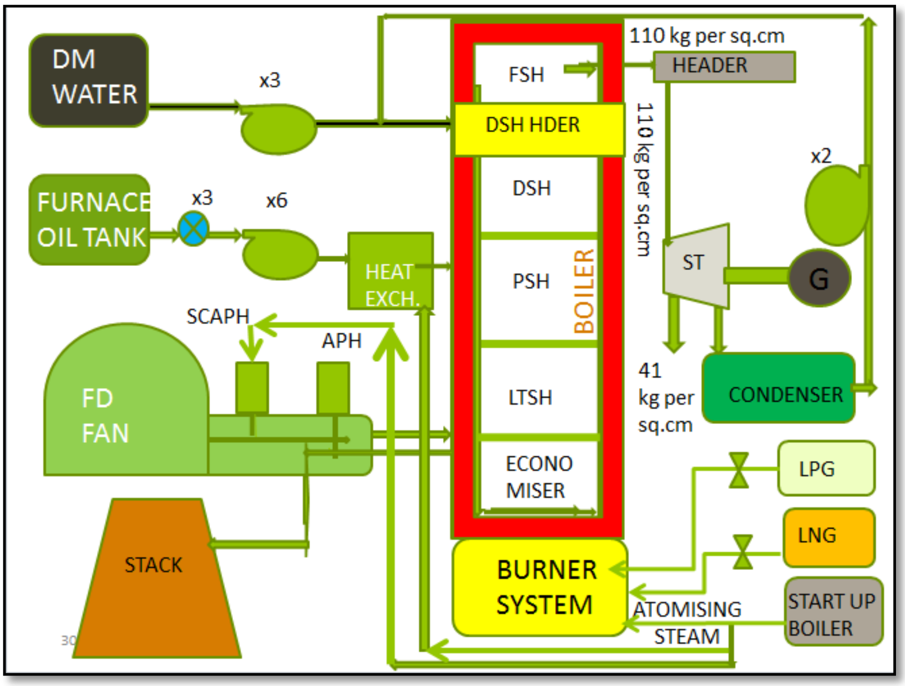


Fig 5 : Modified Layout of Captive Power Plant

VII. Calculation of System Reliability and Availability

There are three arrangements of reliability block diagrams .

1. Series Arrangement
2. Parallel Arrangement
3. Hybrid arrangement

In Series Arrangement , Reliability Block Diagrams are connected in series .Shown in figure 5 is a simple series arrangement of three components each having a reliability of 0.90 Then System reliability $R_{s(t)} = R_{1(t)} \times R_{2(t)} \times R_{3(t)}$

Where $R_{s(t)}$= System Reliability for given time "t ".

$R_{1....n(t)}$ = Reliability of subsystem components from 1…n for given time (t)

Ref Fig -6 for Series arrangement Block diagram.

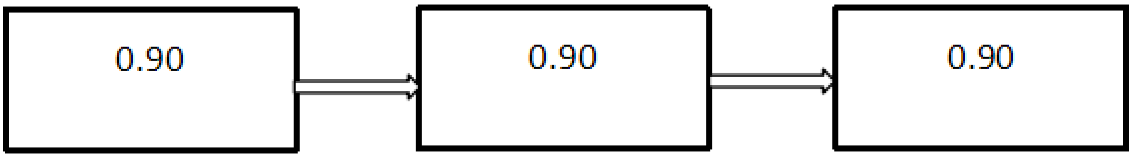


Fig -6 ; Reliability Systems in Series Arrangement

Thus System Reliability $R_{s(t)} = 0.9 \times 0.9 \times 0.9 = 0.729$

In Parallel Arrangement Reliability Block Diagrams are connected in parallel to each other .Shown in figure is a simple parallel arrangement of three components each having a reliability of 0.90 .Then System reliability

$R_{s(t)} = 1- [(1-R_{1(t)}) \times (1-R_{2(t)}) \times (1-R_{3(t)})]$

$R_{s(t)} = 1- [(1-0.9) \times (1-0.9) \times (1-0.9)]$

$= 1-[0.1 \times 0.1 \times 0.1]$

$= 0.999$

Refer Fig. 7 for Parallel arrangement of Reliability block diagrams .

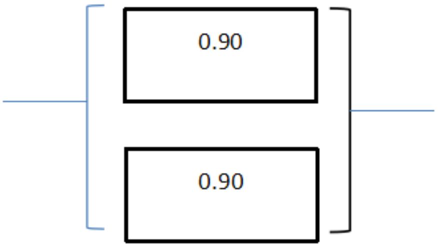


Fig -7; Reliability Systems in Parallel Arrangement

In hybrid arrangement, the RBD has both series and parallel arrangements of block diagrams .While calculating the system reliability and availability of such arrangements it is necessary to calculate reliability and availability of parallel arrangement first and then connect the entity with series blocks such that final calculation will be that of combined and simplified series arrangement .Refer Fig -8 for the hybrid arrangement.

a) Evaluation of system SystemReliability of parallel arrangement is as below.

$R_{s(t)}$ = 1- [(1-0.9)x (1-0.9) x (1-0.9)]
= 1-[0.1 x 0.1 x 0.1]
= 0.999
System Reliability = 0.9 x 0.9 x 0.9 x 0.999 =0.72171

b) Evaluation of system System Reliability of Hybrid Arrangement is as below.
$R_{s(t)Hybrid} = 0.9x0.9x0.9x0.999 = 0.72171$

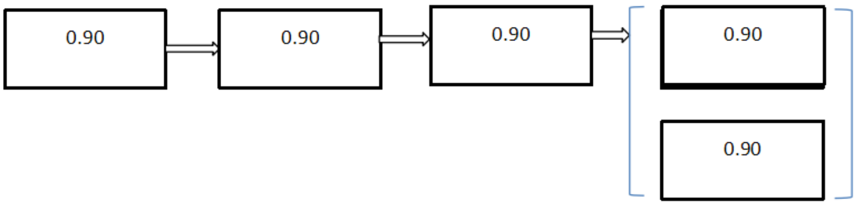


Fig -8: Reliability Systems in Hybrid Arrangement

VIII. Calculation of System Reliability and Availability before modification

There are 31 individual subsystems/components identified as power plant components for analysis.The reliability and availability of those components are calculated individually. The calculated values are given in Table - 9.The system reliability and availability are evaluated and the obtained values are
System reliability before modification = 0.0027
System availability before modification =0.9085
Refer Fig -9 for the Reliability Block Diagram(RBD) before modification.

Table 9 : Reliability and availability before modification

Sl No.	CPP COMPONENTS	**MTBF (HRS)**	**MTTR (Hrs)**	**Availability**	**Failure rate(λ)**	**λ *t**	**Reliability =1/(e ^λ *t)**
1	FWP1	7500	4	0.9995	0.00013333	0.096	0.9085
2	FWP2	7000	4	0.9994	0.00014286	0.10285714	0.9023
3	FWP3	7800	4	0.9995	0.00012821	0.09230769	0.9118
4	BOILER	3000	8	0.9997	0.00033333	0.24	0.7866
5	STEAM HEADER	4400	3	0.9993	0.00022727	0.16363636	0.8491
6	STEAM TURBINE	4400	48	0.9892	0.00022727	0.16363636	0.8491
7	CONDENSER	5000	8	0.9984	0.0002	0.144	0.8659
8	COND. PUMP 1	3000	4	0.9987	0.00033333	0.24	0.7866
9	COND. PUMP 2	3000	4	0.9987	0.00033333	0.24	0.7866
10	STRAINER 1	2000	3	0.9985	0.0005	0.36	0.6977
11	STRAINER 2	2000	3	0.9985	0.0005	0.36	0.6977

12	STRAINER 3	2000	3	0.9985	0.0005	0.36	0.6977
13	FUEL PUMP 1	4000	4	0.9990	0.00025	0.18	0.8353
14	FUEL PUMP 2	4000	4	0.9990	0.00025	0.18	0.8353
15	FUEL PUMP 3	4000	4	0.9990	0.00025	0.18	0.8353
16	FUEL PUMP 4	4000	4	0.9990	0.00025	0.18	0.8353
17	FUEL PUMP 5	4000	4	0.9990	0.00025	0.18	0.8353
18	FUEL PUMP 6	4000	4	0.9990	0.00025	0.18	0.8353
19	HEAT EXCHANGER	3000	8	0.9973	0.00033333	0.24	0.7866
20	FD FAN	4400	16	0.9964	0.00022727	0.16363636	0.8491
21	SCAPH	3000	14	0.9954	0.00033333	0.24	0.7866
22	APH	3000	14	0.9954	0.00033333	0.24	0.7866
23	FSH	5000	48	0.9905	0.0002	0.144	0.8659
24	DSH	5500	48	0.9913	0.00018182	0.13090909	0.8773
25	PSH	8500	48	0.9944	0.00011765	0.08470588	0.9188
26	LTSH	6000	48	0.9921	0.00016667	0.12	0.8869
27	ECONOMISER	5000	48	0.9905	0.0002	0.144	0.8659
28	START UP BOILER	4000	24	0.9940	0.00025	0.18	0.8353
29	LPG-FO-ATM STEAM BURNER SYSTEM	3000	6	0.9980	0.00033333	0.24	0.7866
30	CHILLED WATER SYSTEM3700		5	0.9980	0.00027027	0.19459459	0.8232
31	PIPING	5000	4	0.9992	0.0002	0.144	0.8659

The CPP components in the reliability block diagram are Feed water pumps,Boiler,Steamheader,Steam turbine, Condenser, Condenser pumps,De-aerator,Strainers,Fuel pumps,Heat exchanger,Forced Draught Fan,Steam coil Aitr pre heater (SCAPH), Air pre heater, De-Super heater,Final Super heater,Platen super heater,Low temperature super heater,Start upboiler,Economiser, LPG-Furnace oil burner,Atomizer,Valve system

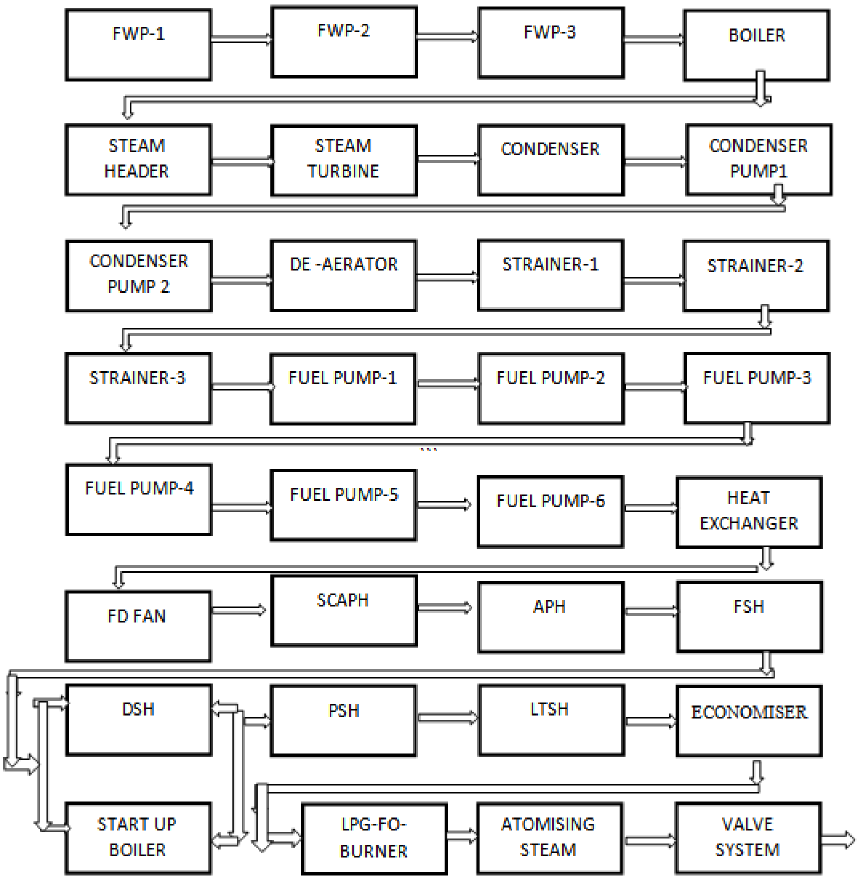


Fig- 9: Reliability Block Diagram BeforeModification

IX. Calculation of System Reliability and Availability after modification

The system reliability and availability after modification is calculated with the help of Reliability Block Diagrams as shown in Fig-10.The newly introduced LNG burner system is added in parallel to the existing LPG Burner system.

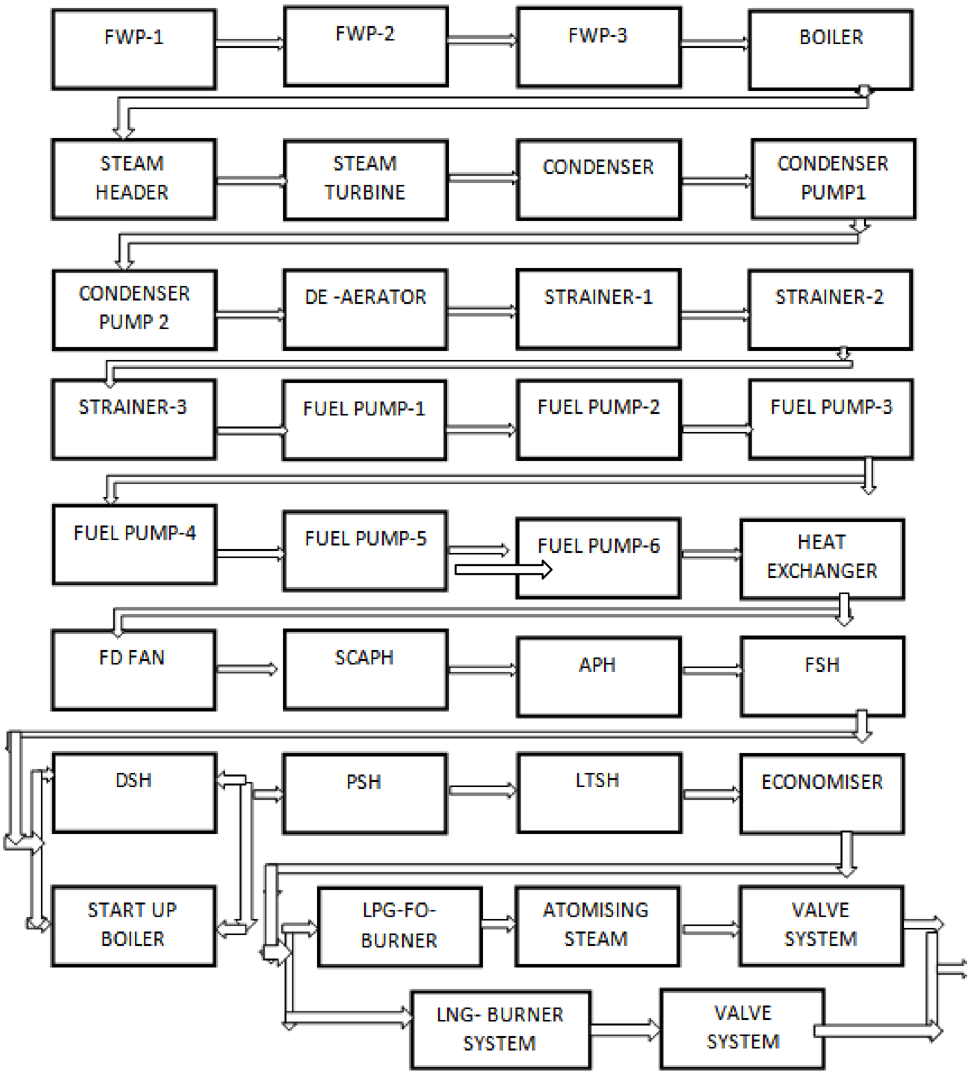


Fig- 10: Reliability Block Diagram After Modification

There are 3 individual subsystems/ components that have got an impact on reliability/availability on account of the modification. They are boiler, piping and LNG burner system identified with improved reliability The obtained values are given in Table - 10.The system reliability and availability after modification are evaluated and the obtained values are:

System reliability after modification = 0.003789

System availability after modification =0.9243

The modification improves the system in terms of reliability and availability .The percentage improvement in System reliability is 1.85% and percentage improvement in System availability is 39.45 % .For reliability calculation , time period “t” is taken as 720 hours.

Table 10 – Reliability and Availability of modified individual components after modifications

Sl No.	CPP COMPONENTS	MTBF(Hrs)	MTTR(Hrs)
1	BOILER	5000	8
2	LNG BURNER SYSTEM	7000	3
3	PIPING	7000	4

X. Calculation of Process System Value and Pay back period

The data for Process System Value calculation is given in Table 11 .The value is calculated using Equationn (10) given in Section 2 .

Process System Value, $V_C = [A_M(RHU - O_M) - A_S(RHU - O_S)]\ (P/A,i,n) - C$

The system availability before modification is 0.9045 (Refer Section 7) and system availability after modification is 0.9243(Refer Section 8).

V_C=[0.9243((60*8000*2100)-161000000)-0.9085(60*8000*2100)-182000000](0.9823)-60000000= INR 2.7 x 10^8

Table 11 . Data for Vc calculation in Case 1 (When LNG Price is USD 14.5 per MMBTU)

System Availability after modification , A_M	***0.9243***
System Availability before modification, A_S	*0.9085*
Production rate IN Tonneper hour ,R	*60*
Hours of Operartion per Year ,H	*8000*
Price per unit process output in INR ,U	*2100*
Operational and Maintenance Cost after modification, O_M	*161000000*
Operational and Maintenance Cost before modification, O_S	*182000000*
Rate of Interest ,i	*9%*
Life Expectancy in Years ,n	*25*
Cost of Modification in INR , C_m	*60000000*
ProcessSystemValuein INR , V_C	*2.7 X*10^8 *[Positive]*

The total hours of operation per year, H is8000 hours . The hourly production rate ,R is 60 TPH.The price per unit process output ,U is INR2100.The rate of interest i = 9% and the cost of modification C = INR 60000000.The operational and maintenance cost per year after modification is INR 161000000 where as operational and maintenance cost per year before modification is INR 182000000.With the available data the calculated change in process system value due to modification is found to be INR 2.7 x 10^8

The obtained value of Change in process system value is positive , hence reliability allocation process is not required .The positive value of process system value indicate that the modification cost is recoverable and the investment will earn profit .The total cost of modification is INR 6 0000000. The expected annual savings is INR 2100000 per year .The life expectancy of the captive power plant is considered 25 years.

Simple Pay Back Period can be evaluated as the ratio between Total cost of modification to Expected annual savings

i.e. Simple Pay Back Period = $\dfrac{60000000}{21000000}$ = 2.98 Years

The process evaluation model enable us to accurately determine the payback period from the plot between Life expectancy in Years and Process System Value in each year .The value obtained from the plot is different from the simple payback period .The accurate payback periodincorporating reliability and availability is found to be 2.4 years .Ref Fig -10 for the plot.The data for plotting fig 10 is given in Table 12.

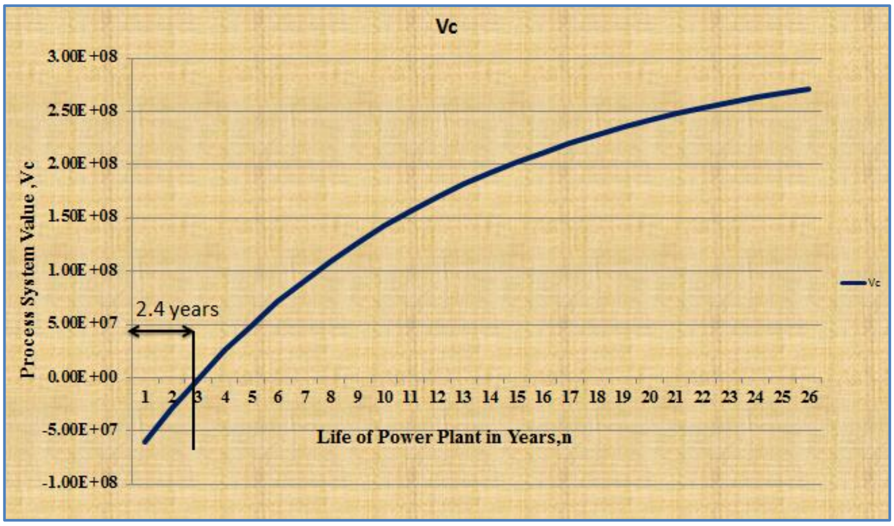


Fig.10: Plot of Process System Value ,"Vc"vs Life of Power Plant in Years,"n"

(Case 1: LNG price = USD 14.5 per MMBTU as on August 2013)

Table 12 –Data for plot between Process System Value ,”Vc“vs Life of Power Plant in Years,”n”in Case 1

n	**Am**	**As**	**R**	**H**	**U**	**Om**	**Os**	**P/A,i,n**	**Cm**	**Vc**
0										-6.00E+07
1	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	0.917431	6.00E+07	-2.91E+07
2	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	1.759111	6.00E+07	-6.67E+05
3	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	2.531295	6.00E+07	2.54E+07
4	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	3.23972	6.00E+07	4.93E+07
5	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	3.889651	6.00E+07	7.12E+07
6	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	4.485919	6.00E+07	9.13E+07
7	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	5.032953	6.00E+07	1.10E+08
8	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	5.534819	6.00E+07	1.27E+08
9	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	5.995247	6.00E+07	1.42E+08
10	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	6.417658	6.00E+07	1.56E+08
11	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	6.805191	6.00E+07	1.70E+08
12	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	7.160725	6.00E+07	1.82E+08
13	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	7.486904	6.00E+07	1.93E+08
14	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	7.78615	6.00E+07	2.03E+08
15	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	8.060688	6.00E+07	2.12E+08
16	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	8.312558	6.00E+07	2.20E+08
17	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	8.543631	6.00E+07	2.28E+08
18	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	8.755625	6.00E+07	2.35E+08
19	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	8.950115	6.00E+07	2.42E+08
20	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	9.128546	6.00E+07	2.48E+08
21	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	9.292244	6.00E+07	2.53E+08
22	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	9.442425	6.00E+07	2.58E+08
23	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	9.580207	6.00E+07	2.63E+08
24	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	9.706612	6.00E+07	2.67E+08
25	0.9243	0.9085	60	8640	2100	1.61E+08	1.82E+08	9.82258	6.00E+07	2.71E+08

The payback period from the plot is less than the simple pay back because the availability of the power plant after modification is more than the availability of the power plant before modification.

XI. Impact of LNG Price Variation onthe Process System Value of the modification

The discussion until now was the scenario of the modification implementation at an LNG price of USD 17.4 per MMBTU in the beginning of August 2013.As per the situation in the mentioned time the change in process system value of the modification is positive .The modification cost was recoverable and the project will yield profits. However due to socio- political and economic conditions, the supply price of LNG is raisedto 24.75 USD per MMBTU as and the price remains the same value of USD24.75 as on April 2014 .The impact of the price variation can be analyzed using the process evaluationmodel .The increase in price has caused about 45% in operational cost thus the new value of operational and maintenance cost is INR 23,345,000.

Refer Table 13 for the new set of data for process evaluation model .

The value is calculated using Eqn (10) given in Section 2 .

$V_C = [A_M(RHU – O_M) -A_S(RHU – O_S)] (P/A, i ,n) – C_m$

The system availability before modification is 0.9045 and system availability after modification is 0.9243 .

V_C=[0.9243((60*8000*2100)-233450000)-0.9085(60*8000*2100)-182000000](0.9823)-60000000

= -9.1 x 10^7 [Negative]

Table 13 . Data for Vc calculation in Case 2(When LMG Price is 24.75 USD per MMBTU)

System Availability after modification ,A_M	***0.9243***
System Availability before modification,A_S	*0.9085*
Production rate IN Tonneper hour ,R	*60*
Hours of Operartion per Year ,H	*8000*
Price per unit process output in INR ,U	*2100*
Operational and Maintenance Cost after modification,O_M	233450000
Operational and Maintenance Cost before modification,O_S	*182000000*
Rate of Interest ,i	*9%*
Life Expectancy in Years ,n	*25*
Cost of Modification in INR ,C_m	*60000000*

ProcessSystemValuein INR ,V_C	*- 9.1 x 10^7 [Negative]*

Since the change in process system value is negative , the modification cost cannot be recovered and the project will not earn profits due to the socio economic and political situations . When the graph is plotted for n=1 to 25 , the line of value Vc is parting away from the X-Axis and is not showing any improvement over the period if the LNG supply price is USD 24.75 MMBTU .ReferFig 11 for plot andTable 14 for data for plot.

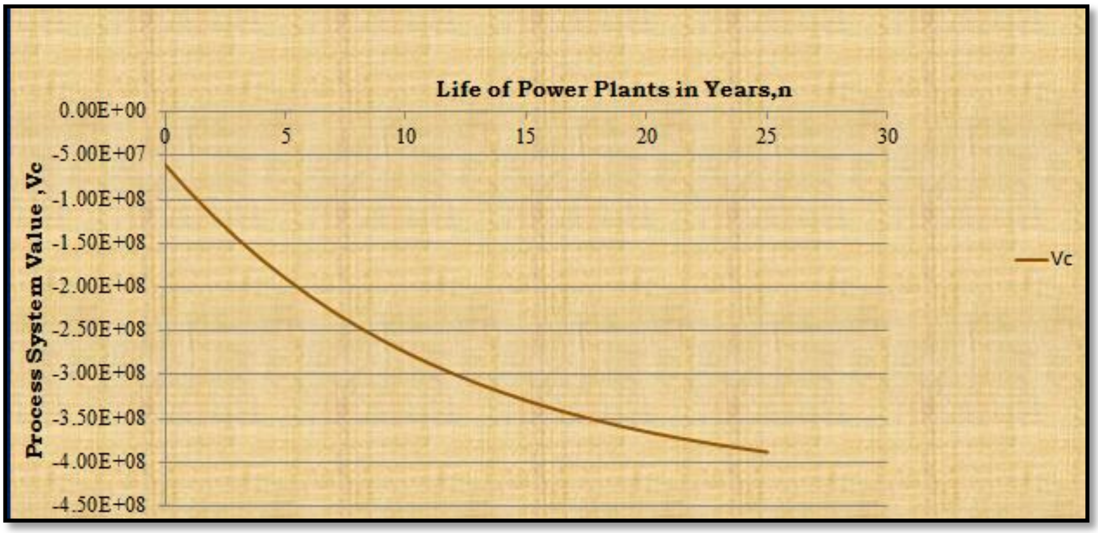


Fig 11 : Plot of Process System Value ,”Vc” vs Life of Power Plant in Years,”n”

(Case 2 : LNG price = USD 24.75 per MMBTU as on April 2014

Table 14 – Data for plot between Process System Value ,”Vc“vs Life of Power Plant in Years,”n”in Case 2

n	Am	As	R	H	U	Om	Os	P/A,i,n	Cm	Vc
0										-6.00E+07
1	0.9243	0.9085	60	8640	2100	1.61E+08		0.917431	6.00E+07	-9.06E+07
2	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	1.759111	6.00E+07	-1.19E+08
3	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	2.531295	6.00E+07	-1.45E+08
4	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	3.23972	6.00E+07	-1.68E+08
5	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	3.889651	6.00E+07	-1.90E+08
6	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	4.485919	6.00E+07	-2.10E+08
7	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	5.032953	6.00E+07	-2.28E+08
8	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	5.534819	6.00E+07	-2.45E+08
9	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	5.995247	6.00E+07	-2.60E+08
10	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	6.417658	6.00E+07	-2.74E+08
11	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	6.805191	6.00E+07	-2.87E+08
12	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	7.160725	6.00E+07	-2.99E+08
13	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	7.486904	6.00E+07	-3.10E+08
14	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	7.78615	6.00E+07	-3.20E+08
15	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	8.060688	6.00E+07	-3.29E+08
16	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	8.312558	6.00E+07	-3.38E+08
17	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	8.543631	6.00E+07	-3.45E+08
18	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	8.755625	6.00E+07	-3.52E+08
19	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	8.950115	6.00E+07	-3.59E+08
20	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	9.128546	6.00E+07	-3.65E+08
21	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	9.292244	6.00E+07	-3.70E+08
22	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	9.442425	6.00E+07	-3.75E+08
23	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	9.580207	6.00E+07	-3.80E+08
24	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	9.706612	6.00E+07	-3.84E+08
25	0.9243	0.9085	60	8640	2100	1.61E+08	2.34E+08	9.82258	6.00E+07	-3.88E+08

Refer Fig 12 for combined plot between Case 1 and Case 2.

Case 1: LNG price = USD 14.5 per MMBTU as on August 2013

Case 2 : LNG price = USD 24.75 per MMBTU as on April 2014

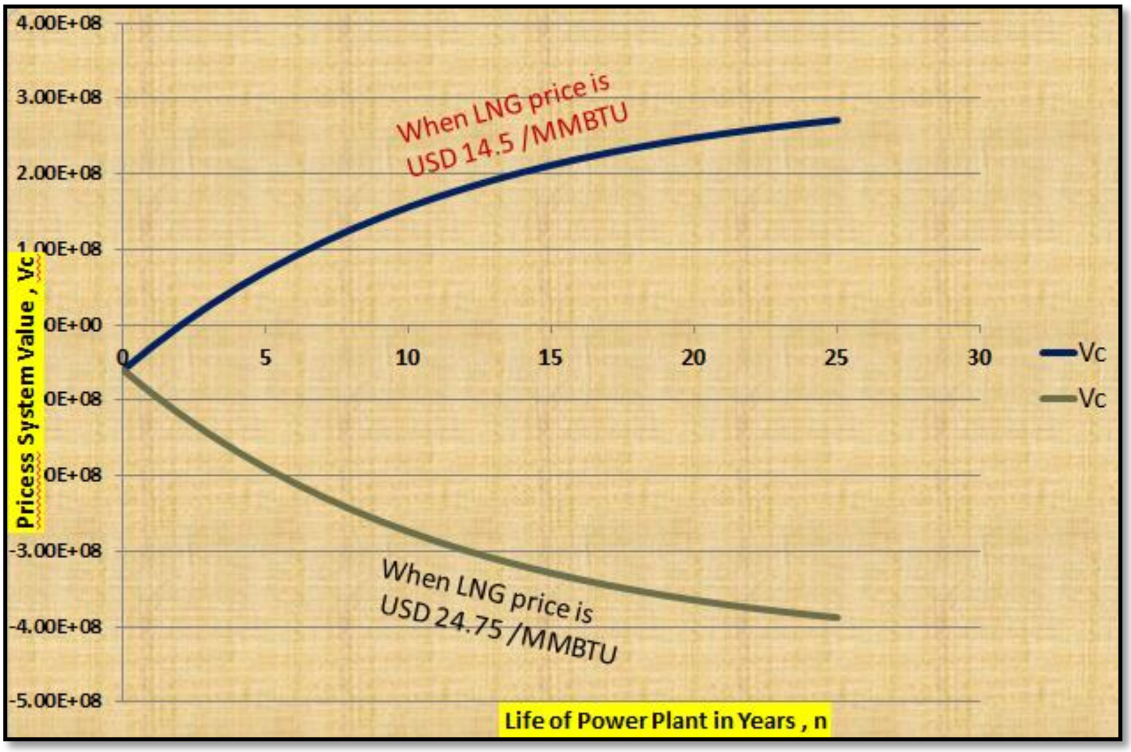


Fig 12 : Combined Plot of Process System Value ,"Vc" vs Life of Power Plant in Years,"n"
(Case 1: LNG price = USD 14.5 per MMBTU as on August 2013)
(Case 2 : LNG price = USD 24.75 per MMBTU as on April 2014)

XII. Results And Discussions

This research paper extract following results.

Case 1:When LNG supply price is 14.5 USD per MMBTU

1.System Availability before Modification , As= 0.9085
2.System Reliability before Modification , Rs=0.002717
3.System Availability After Modification,Am=0.9243
4.SystemReliabilty After Modification Rm=0.003789
5. Percentage Improvement in System Availability =1.85%
6. Percentage Improvement in System Reliability =39.45%
7. Change in Process System Value = INR 2.7 x 10^8
8. Simple Pay back period= 2.98 years
9.Pay back period incorporating reliability and availability=2.4 years

Case 2:When LNG supply price is 24.75 USD per MMBTU

1.System Availability before Modification , As= 0.9085
2.System Reliability before Modification , Rs=0.002717
3.System Availability After Modification,Am=0.9243
4.SystemReliabilty After Modification Rm=0.003789
5. Percentage Improvement in System Availability =1.85%
6. Percentage Improvement in System Reliability =39.45%
7. Change in Process System Value = - 9.1 x 10^7 [Negative]
8. At supply price of LNG @24.75 USD per MMBTU ,running the modified plant with LNG will yield loss . Hence the fuel to continue with furnace oil until the price issues are resolved.

The system availability and reliability shows improved values after modification .The system availability and reliability values before modification are 0.9085 and 0.002717 .The system availability and reliability after modification are 0.9243 and 0.003789 .The percentage improvement in System availability is 1.85% where as Percentage improvement in System reliability is 39.45% .The higher percentage of system reliability shows the LNG conversion modification will optimize the system from a technical point of view.But commercially , due to socio political and economic conditions , the higher supply price of LNG as adversely affecting the modification implementation as running the plant art the current supply price will yield loss.The initial rate of 14.5 USD per MMBTU was a better price as it will give pay back in 2.4 years against a simle payback period of 2.98 years .It indicates that the modification will definitely result in improved system efficiency from an engineering point of view at an optimized rate of LNG price .

XIII. Recommendations

1.It is recommended to implement the process evaluation model in power plants to evaluate impact of modifications in terms of reliability,availability , payback period incorporating reliability and availability and impact of variations in LNG (fuel) prices.

2.It is necessary to install one more Forced Draft fan in addition to the existing one for redundancy as the system before and after modification has only one FD fan per boiler .If the FD fan fails it will lead to plant shut down .

3.The LNG price need to be stabilized at the rate or lower of 14.5 USD per MMBTU for the economic performance of the modified plant.

XIV. Conclusions

The presented paper attempt to study the modifications on the existing plant for the LNG conversion from furnace oil fired boiler ..The individual component/subsystem reliability and availability are calculated and also the system reliability and availability before and after modification are also evaluated .The improved system reliability and availability indicate that the modifications will improve the performance of the modified plant .

The process system value evaluation model remains as an efficient tool in determining the process system value of the power plant .During the modification implementation phase, the process system value is positive in Case 1 where LNG supply price is 14.5 USD per MMBTU which demonstrate that the modification cost is recoverable.. However due to socio- political and economic reasons the LNG supply price was increased to 24.75 USD per MMBTU during the running phase of the modified plant. The impact of increased price was evaluated using the process evaluation model and observed that the new price will incur loss if the captive power plant is allowed to run with LNG after modification .Thus the impact of modifications in De super and flame burner system on the process system value of the 7MW captive power plant was assessed using the evaluation model and also impact of variation in fuel price is also assessed using the same model.

Nomenclature

ABEP	break even availability of modified process system
Ai	steady state availability
AS	process system availability
b	pay back period
C	cost of process system components and equipments
Cm	cost of additional equipments towards modification
E	expected yearly savings due to modification
G	expected percentage growth of operating and maintenance cost per year
H	system operating hours in year
i	interest rate
M	maintenance cost for first year
MTBF	mean time between failure
MTTR	mean time to repair
n	expected life of process system in years
O	operating cost for first year
P/A	present value given annual rate
R	hourly production rate
RBD	reliability block diagram
R(t)	reliability expressed as function of time
U	unit price of process output
V	process system value
VC	change in process system value
Z(t)	failure rate expressed as function of time
k	constant failure rate
l	constant mean repair rate

INR	IndianRupees
USD	US Dollars

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