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Review Article

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Energy Efficiency Improvement through Innovative & In-House Energy Saving Schemes in NRL Co-Generation Plant

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Abstract

Energy conservation has emerged as one of the major issues in the recent years due to the increasing gap between the ever rising demand & the limited supply of energy. Energy requirement in our country is increasing in a very rapid rate. Conservation and efficient utilization of energy resources is the first and most important step towards narrowing down this gap. The more energy we save today, the more is left for our children tomorrow!

Energy is the main driving force of economic growth of a country. Tomorrow's economic growth depends upon today's efficient & effective use of energy. Hence, energy conservation & the practical application & creating awareness of energy efficient methods are very much essential for the sustenance & development of a modern economy of the country.

Keeping in view the importance of the energy efficiency & conservation, following innovative schemes have been developed in the Power and Utility Department of NRL, which are completely indigenous and in-house. They are developed during trouble shooting of the plant related problems. Also those areas of the plants are identified which has the potential for good amount of energy recovery, which otherwise would have been a loss. Apart from the successful solutions to the problems, they have resulted in the process optimization and hence improving the Energy Efficiency. In this paper, following schemes have been described, which together leads to a monetary savings of approx. 22.51crore rupees per annum.

The schemes are as follows

Schemes	Title	Annual Monetary Benefit
1	UB & HRSG burner pilot header modification	0.73 lakh
2	GTG NG MP steam heater replacement with LP steam	7.50 lakh
3	Condensate recovery from LP dumping station	63.34 lakh
4	LP steam & condensate recovery from steam traps	76.22 lakh
5	Modification in CGP BFW system	100.32 lakh
6	Power generation through NG Turbo Expander	2002.83 lakh
	Total Annual Savings	**2250.94 lakh (INR)**

This complete paper is subdivided into

- Brief introduction of Numaligarh Refinery Limited (NRL)
- NRL Co-Generation Plant (CGP) configuration
- Detail description of the schemes
- Pre and post modification changes after implementation of the schemes
- Dis-advantages, Short comes and Losses before modification
- Advantages and Profits after modification
- Data analysis and Calculation
- Improvements in the CGP operation
- Conclusion

Brief introduction of Numaligarh Refinery Limited (NRL)

Nestling in the sylvan environs of the Brahmaputra valley where the beautiful rendezvous of water and land throws up myriad colours, **Numaligarh Refinery Limited (NRL)**, which was set up at Numaligarh in the district of Golaghat (Assam) in accordance with the provisions made in the historic Assam Accord signed on 15th August 1985, has been conceived as a vehicle for speedy industrial and economic development of the region.

The 3 **MMTPA** Numaligarh Refinery Limited was dedicated to the nation by the erstwhile **Honourable Prime Minister Shri A. B. Vajpayee on 9th July, 1999**. NRL has been able to display creditable performance since commencement of commercial production in October, 2000. It is located at Morangi, Golaghat district, Assam in India is a refinery owned by Numaligarh Refinery Limited, a joint venture between Bharat Petroleum (61.65%), Oil India (26%) and Govt of Assam (12.35%).With its concern, commitment and contribution to socio-economic development of the state combined with a track record of continuous growth, NRL has been conferred the status of Mini Ratna PSU.

Product Range

Our product range includes LPG, Naphtha, Motor Spirit (MS), Aviation Turbine Fuel (ATF) Superior Kerosene Oil (SKO) High Speed Diesel (HSD), Raw Petroleum Coke (RPC) Calcined Petroleum Coke (CPC), Sulphur, Wax, Nitrogen, Mineral Turpentine Oil (MTO), Special Boiling Point Spirit (SBPS) and Liquid Sulphur.

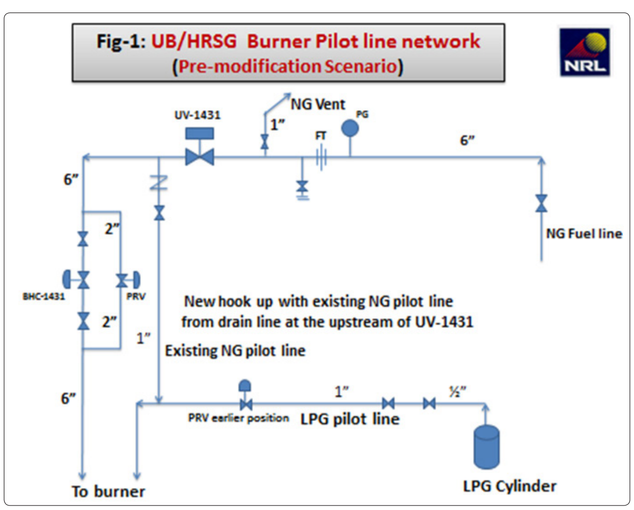
NRL Co-Generation Plant (CGP) configuration

In Co-Generation Plant (CGP) or Captive Power Plant (CPP) of Numaligarh Refinery Limited, there are two nos. Gas Turbines (GTG-01 and GTG-02) along with HRSGs, one Steam Turbine Generator (STG) and one Utility Boiler (UB) in Co-Generation Plant to meet refinery power & steam demand.

Design capacities are: GTG of 30 MW each originally,but both GTG-1 in April'2015 and GTG-2 in September'2016 have been up-rated and now expected to yield 34 MW each, STG of 12 MW and Utility Boiler of 53TPH. Each GTG has downstream Heat Recovery Steam Generators (HRSG) of capacity 130 TPH (with supplementary firing) which recovers heat from the Gas turbine hot exhaust flue gases.

Description of Schemes in Details
Scheme-1
UB/HRSG Burner Pilot line modification
UB & HRSG Burners Pilot line before modification

NRL Co-Generation plant has one Utility Boiler (UB) and two nos. of Heat Recovery Steam Generators (HRSG). Fuels used in UB are Naphtha, Industrial Fuel Oil (IFO), Natural Gas (NG) and Refinery Fuel Gas (FG) while HRSGs are provided with supplementary firing of Naphtha, NG and Refinery FG. The inbuilt pilot burner source of both the boilers is LPG.



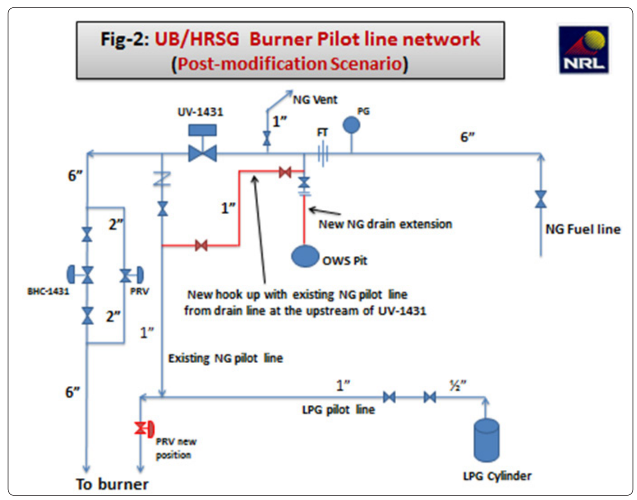
Problems faced in pre-modification period

Firstly, when the burner could not be lit up after some repeated trials, then slowly LPG cylinder pressure starts to decrease, thereby LPG pilot header pressure reduces. This then creates problems in the initial lit up of burner pilot burner. This condition often brings emergency as LPG cylinders have to be transferred from running boiler to the other stand-by boiler immediately. So in case of an emergency situation, this creates another added emergency.

Secondly, the tapping of Natural Gas (NG) pilot line that connects with LPG pilot line is from the downstream of the NG shut-off valve (UV-1431), shown in fig1 below in case of HRSG fuel circuit. So the NG pilot line cannot be used for burner lit up purpose without opening the shut-off valve.

Modification Carried Out

A very simple modification was carried out.
Firstly, hook up of the existing NG pilot line with the NG vent line or drain line i.e., from the upstream of the shut-off valve UV-1431, (shown in diagram in case of HRSG fuel circuit.).
Secondly, PRV of LPG header is repositioned at the LPG & NG common downstream pilot header.



The advantages of this hook-up are

1. Now both LPG and NG pilot sources of burners are interchangeable.
2. Brought flexibility and reliability of the pilot source because NG is available all the time (except NG shutdown) that too with sufficient pressure (4.0 kg/cm2) at the upstream of the PRV. In comparison to that, LP cylinder pressure starts to drop after some repeated failure/unsuccessful attempts of burner firing.
3. LPG Consumption is reduced to almost nil (except during NG shutdown period).
4. No emergency situation due to pilot source.
5. Monetary gain (**73361.28 rupees/year**).

Calculation part

On an average 7 nos. of commercial LPG Cylinders were required for both the boilers per month.

So, cost incurred = 7 nos. cylinders * 1120 rupees/cylinder
= **7840.00 rupees/month**

Mass of total 7 cylinders used = 7*19 kg = 133 kg/month

(Mass * GCV) of LPG = (Mass * GCV) of NG
(7*19kg) * 11900 kCal/kg = (M*9600 kCal/kg)
M = 143.88 kg;

So, 143.88 kgof equivalents NG are required against 133 kg of LPG per month.

Now cost of 164.864 kg of NG = 143.88*12 rupees/kg in one month
= **1726.56 rupees/month**

So, money saved on using NG = 7840.00 – 1726.56
=6113.44 rupees/month
= **73361.28 rupees/year**

For information

- 11900 kCal/kg (LPG GCV)
- 11000 kCal/kg (NG GCV)
- LPG price = 1120 rupees/cylinder ; (commercial cylinder of 19 kg each)
- NG = approx. 12.00/kg.

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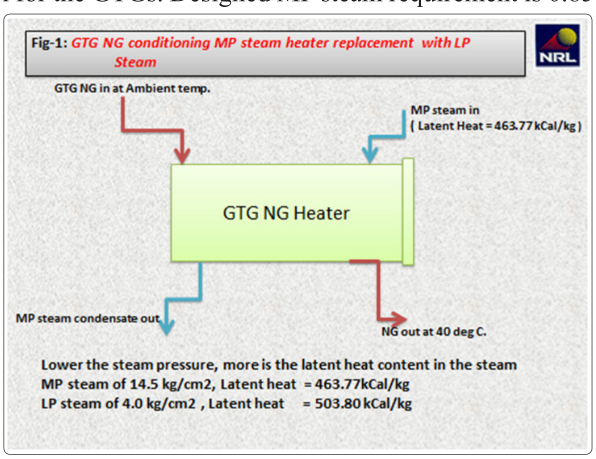
Scheme-2
Steam Optimization - Utilization of Steam at Lower Pressure for heating purpose
Scheme-2
Gas Turbine Generator (GTG) NG conditioning Medium Pressure (MP) steam heater replacement with Low Pressure (LP) steam

In NRL CGP, there is a Natural Gas conditioning skid, where there exists two nos. of NG heater to increase and maintain the NG temperature at around 40 deg C. One is a MP steam heater and the other is an electric heater.

The MP steam heater uses steam at pressure 14.5 kg/cm^2 to raise the NG temperature from ambient to 40 deg C. This NG is then used as fuel for the GTGs. Designed MP steam requirement is 0.85 T/h.



In CGP, 3 types of steam are produced. First one is the High Pressure (HP) steam which is generated by UB & HRSG at 40.0 kg/cm2 & 450 deg C. This HP steam is then let down to Medium Pressure (MP) steam at 14.5 kg/cm2 & 250 deg C at Pressure Reducing and De-superheating Station-I (PRDS-I), which is further reduced to Low Pressure (LP) steam as 4.0 kg/cm2 & 185 deg C at PRDS-II.

By using the principle, **"Lower the steam pressure, higher is the Latent heat of vaporization, which is used for heating purpose"**; if MP steam is replaced by LP steam in the NG heater, then it is seen that 583.57 T/year of steam is saved which in monetary terms, gives approx. **7.24 lakh/annum**. The details of the comparisons of the two steams are tabulated below:

Parameters	LPS	MPS	Units	
Pressure	4	14.5	kg/cm^2	
Temp	190	250	deg C	
Latent Heat	503.804	463.77	kCal/kg	
		40.034	kCal/kg	
		0.85	T/h	MPS flow through NG Heater
		20.4	T/day	**MPS**
		20400	kg/day	**MPS**
		9460908	kCal/day	Energy reqd. per day
	=9460908/503.804 =18778.95		kg/day	**LPS**
	18.77895		T/day	**LPS**
	1.621054		T/day savings	
	48.63163		T/month savings	
	583.5795		**T/year savings**	
	724222.2		**rupees/year savings**	**If LPS is used in place of MPS**

(@ Steam cost = 1241 rupees/T)

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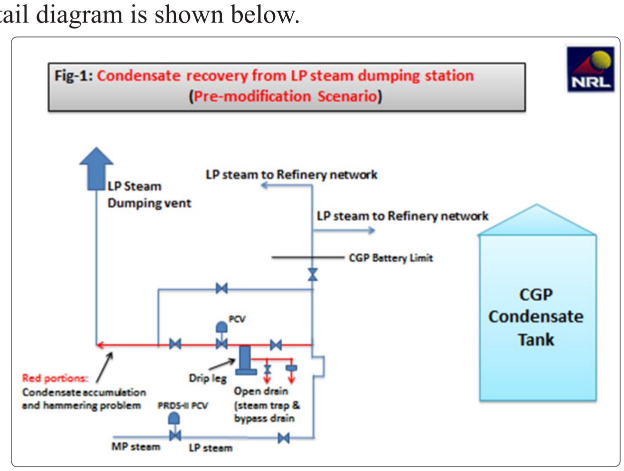
Scheme-3
Condensate & Heat Energy recovery from LP steam dumping station
Introduction

In CGP, there is a Low Pressure (LP) steam dumping station at the battery limit of the CGP, before the LP steam (4.0 kg/cm^2 & 190 deg C) is discharged to the Refinery network. At the upstream of this dumping station, there exists a Pressure Control valve (PCV) which is kept in Auto mode. This PCV regulates the LP steam pressure of the dumping station. It vents out the LP steam to the atmosphere through a vent when LP steam pressure exceeds more than it's set point. Thus the precious LP steam is lost whenever there is venting. Detail diagram is shown below.



Problems faced before Pre-modification system

From the experience, it is seen that, whenever the LP steam generation or flow from different Refinery Units is on higher side, then the LP steam flow from CGP remains on lower side. Also sometimes, the PRDS-II PCV (where MP steam is let down to LP steam) remains at a very low opening or almost 1.0% to 0% opening due to minimal LP steam flow through it. Due to this, there is a chance of gradual LP steam condensate formation due to low flow and flow stagnancy inside CGP battery limit. Also, sometimes, the LP dumping station PCV opens up as the LP pressure inside CGP increases due to low demand or flow. This leads to venting of LP steam at dumping station.

Again when the Refinery units LP Steam generation decreases, then LP steam flow from CGP PRDS-II increases. In this situation often hammering problem is faced because sudden high LP steam flow strikes and hammers the already accumulated LP steam condensate in the header.

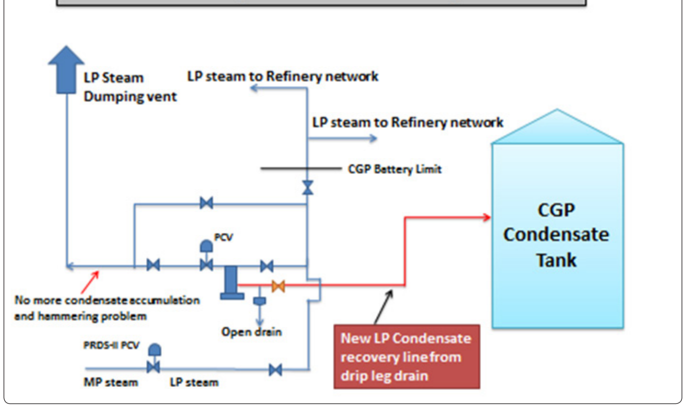
To avoid this situation, the trap by-pass drain of the drip leg of the LP steam header is adjusted to a certain opening such that there is a minimum LP steam condensate flow through it, thereby reducing the chance of condensate accumulation. So there is a continuous loss of precious hot LP condensate to open drain.

Post-Modification system

A very simple and minimal modification is carried out in which ajust simple **tap-off is taken from the LP dumping station drip leg** and routed to the CGP Condensate Tank.

After this modification, the trap by-pass drain opening is now kept completely closed. With the new tap-off, the hot LP condensate is diverted to CGP Condensate tank. This hot condensate is then transferred finally to the De-aerator along with the other steam condensate. This helped to recover the hot LP steam condensate and also decreased the possibility of condensate accumulation and in the process; there is no more chance of hammering problem when CGP LP steam flow suddenly increases.

Fig-2: Condensate recovery from LP steam dumping station (Post-modification Scenario)



Advantages of the scheme

- Increased the Condensate temperature inside the condensate tank (by 15 to 25 deg C).
- Reduced the De-aerator LP pegging steam flow to about 0.5 T/h.
- Total 10368 T of LP condensate is recovered per year and thus this amount of Boiler De- mineralized Water (DM) water make-up is saved.
- Reduced Boiler chemical consumption.
- Total monetary gain = 63.34 lakh per annum
- Helped in successful trouble shooting of hammering problem of LP steam header inside CGP Battery limit.

Savings Calculation

Average Total LP condensate recovered = 20 Litre/min = 28800 Litre/day = 28.8 T/day = 10368 T/year

Savings on 10368 T condensate = 10368 T * 32.22 rupees/T (@ DMW cost of 32.22 Rupees/T) = **334056.96 rupees/year - (a)**

Heat Content in 10368 T condensate = 25 kCal/kg *10368 *1000 kg (as 25 deg C rise in Condensate tank). = **259200000.00 kCal/year**

So, quivalent LP steam in 259200000.00 kCal= 259200000.00/503.804 kg = **514.485 T**

So, Total savings from 514.485 T of LP Steam = 514.485 T * 1241 rupees/T = **638476.87 rupees ---- (b)**

Again savings from 0.5 T/h LP pegging steam reduction = 0.5 T*24*1241 rupees/T = 14892.00 rupees/day = **5361120.00 rupees/ year ---- I**

Hence, total savings = (a) + (b) +(c)
= 6333653.83 rupees/year
= 63.34 lakh/year

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Scheme-4

Condensate & Flash Steam Recovery from Co-Generation Plant Steam Traps

Introduction to Condensate & Flash steam

Condensate is the liquid formed when steam passes from the vapor to the liquid state.When the latent heat of steam is transferred to heat the product, that steam condenses into water, which is also known as "condensate". When steam condenses, only the latent heat has been lost, and the full amount of sensible heat remains back with the hot condensate.

Flash steam is a name given to the steam formed from the hot condensate when the pressure is reduced. Normal or "live" steam is produced at a boiler, steam generator, or waste heat recovery generator – whereas flash steam occurs when high pressure / high temperature condensate is exposed to a large pressure drop such as when exiting a steam trap.

Importance of Condensate & Flash Steam recovery

Condensate contains a significant amount of sensible heat that can account for about 10% to 30% of the initial heat energy contained in the steam. Reusing as much of this sensible heat as possible is one of the main reasons behind condensate recovery which otherwise would have been wasted, both in the form of money and resources.Feeding the boiler with high-temperature condensate can maximize boiler output because less heat energy is required to turn water into steam.

Flash steam from a high pressure is recovered into a flash tank and re-used as steam in a low pressure system.

Thus, recovering condensate and flash steam, instead of throwing it away can lead to significant savings of

- Fuel/energy costs,
- Leads to less air pollution by lowering CO2, NOx and SOx emissions through fossil fuel reduction.
- Boiler water Chemical treatment, and
- Boiler Water Make-up water.
- Improves the Aesthetic look of the plant as there will be no more flash steam or condensate discharge through the steam traps. So the area looks neat, clean & tidy. Thus 100% re-use or recovery system in the process.

Illustration

Table 1: Low Pressure (LP) steam flashed to atmosphere

Low pr. Condensate & Flash steam				
Abs. Pr.	Sat. temp	Sensible heat of Liquid water	Latent Heat of Evaporation	Total Heat of Steam
(bar)	(deg C)	(kCal/kg)	(kCal/kg)	(kCal/kg)
1	99.1	99(h_2)	539.8 (L_2)	638.8
4	142.9	144 (h_1)	509.7	653.7
Excess Sensible Heat		45		

From the above **Table-1**, 1kg of condensate at 4 bar (abs pr.) with a saturation temperature of 142.9^0 C contains 144.0 kcal/kg of heat (sensible heat). This condensate is discharged via steam trap to atmosphere.

Hot water at atmospheric pressure (1 bar) can contain only 99.0 kCal/kg at saturation temperature of 99.1^{0}C.

Thus, there is an excess Heat Energy (Sensible heat) of 45.0 k Cal/kg. This excess heat is used in heating or boiling that part of the condensate which is converted into flash steam.

% of flash steam recovered = **[(h_1-h_2)/L_2]*100**
= **[(144.0-99.0)/539.8]*100** ; {h1, h2, L2 from the above Table-1}.
= **0.0829*100**
= **8.3 % (pprox...)**

NB. Where: **h_1** is the sensible heat of higher pressure condensate.
H_2 is the sensible heat of the steam at lower pressure (at which it has been flashed).
L_2 is the latent heat of flash steam (at lower pressure).

Thus it is beneficial to recover both LP condensate and flash steam as:

- Heat Energy loss as flash steam = 45 kCal (in 1 kg LP condensate)
- % of Flash steam that would have been recovered = 8.3%
- % of Heat content in 8.3% flash steam = 45/99 = 45.4%
- Though flash steam constitutes only 8.3% of 1 kg LP condensate, but energy wise it contains about 45.4% of the total energy of 1 kg LP condensate.
- So in **1Ton of LP condensate**, Energy saved (in**flash steam**) = 1000*45 = **45000 kCal**

Table 2: Medium Pressure (MP) steam flashed to atmosphere

Low pr. Condensate & Flash steam				
Abs. Pr.	Sat. temp	Sensible heat of Liquid water	Latent Heat of Evaporation	Total Heat of Steam
(bar)	(deg C)	(kCal/kg)	(kCal/kg)	(kCal/kg)
1	99.1	99	539.8	638.8
14	194.1	197	468.7	665.7
Excess Sensible Heat		98		

- Heat Energy loss as flash steam (could be recovered)= 98 kCal (in 1 kg MP condensate)
- % of Flash steam that would have been recovered = [197-99]/539.8 = 0.1815
- = 18.15%
- % of Heat content in 18.15% flash steam = 98/99 = 98.9%
- Thus in 1 kg of MP condensate, though % of flash steam only 18.15% but heat content is very high(98.9%).
- So in **1Ton of MP condensate**, Energy saved (in **flash steam**) = 1000*98 = **98000 kCal**

Table 3: High Pressure (Hp) Steam Flashed To Atmosphere

Low pr. Condensate & Flash steam				
Abs. Pr.	Sat. temp	Sensible heat of Liquid water	Latent Heat of Evaporation	Total Heat of Steam
(bar)	(deg C)	(kCal/kg)	(kCal/kg)	(kCal/kg)
1	99.1	99	539.8	638.8
40	249.2	258	410.7	668.7
Excess Sensible Heat		159		

- Heat Energy loss as flash steam = 159 kCal (in 1 kg HP condensate)
- % of Flash steam that would have been recovered = [258-99]/539.8 = 29.45%
- % of Heat content in 29.45% flash steam = 159/99 = 160.6%
- So in **1Ton of HP condensate**, Energy saved (in **flash steam**) = 1000*159 = **159000 kCal**

Re-use of Condensate and Flash Steam

Condensate can be reused in many different ways, for example

- As heated feed water, by sending hot condensate back to the boiler's de-aerator
- As pre-heat, for any applicable heating system
- As steam, by reusing flash steam
- As hot water, for cleaning equipment or other cleaning applications
- Reusing hot condensate can lead to considerable savings in terms of energy and water resources, as well as improve working conditions and reduce plant's carbon footprint

Flash Steam Can Be Reused In Many Different Ways, For Example

Re-used in a low pressure steam network

- Can be converted into Medium pressure steam through a thermo-compressor
- Heat Exchanger in heating process fluid

- As pegging steam in De-aerator
- Steam Tracing

Potential of Condensate & Flash steam Recovery in CGP

Some areas of CGP or CPP inside the Battery limit have a good potential for the recovery of Condensate & Flash steam from steam traps:

- Area between UB & STG
- Pressure Reducing and De-superheating Station (PRDS) area
- Battery limit
- UB Fuel station

Steps followed during study

(i) Theoretical calculation % of flash steam & Energy content (in Flash steam) in 1 kg of condensate recovered from HP & MP steam traps (if flashed at LP pr. = 4 bar) were done because we need to discharge the flash steam recovered from HP & MP steam traps to the LP steam header or to De-aerator.

Table-4

Low pr. Condensate & Flash steam				
Abs. Pr.	**Sat. temp**	**Sensible heat of Liquid water**	**Latent Heat of Evaporation**	**Total Heat of Steam**
(bar)	(deg C)	(kCal/kg)	(kCal/kg)	(kCal/kg)
4	142.9	144 (a)	509.7	653.7
14	194.1	197 (b)	468.7 (d)	665.7
Excess Sensible Heat		53 (b-a =c)		
% flash steam		**11.30787284** (c/d)*100		

Table-5

Low pr. Condensate & Flash steam				
Abs. Pr.	**Sat. temp**	**Sensible heat of Liquid water**	**Latent Heat of Evaporation**	**Total Heat of Steam**
(bar)	(deg C)	(kCal/kg)	(kCal/kg)	(kCal/kg)
4	142.9	144 (x)	509.7	653.7
40	249.2	258 (y)	410.7 (w)	668.7
Excess Sensible Heat		114 (z= y-x)		
% flash steam		**27.75748722 (z/w)*100**		

Table-6

Flash steam	Flash steam	Energy content
	%	**kCal/kg**
From HP steam	27.75	114.00
From MP steam	11.30	53.00

(ii) Survey of steam traps condition inside CGP Battery limit wasdone.

The breakup of Total nos. of steam traps (38) inside our CGP battery limit:-

HP steam = 8
MP steam = 10
LP steam = 20

In our study, we have covered only four areas (mentioned above) where concentration of steam traps is more. The breakup of steam traps in those four areas is:-

HP steam = 2
MP steam = 8
LP steam = 8

(iii) Amount of average condensate generated from HP, MP & LP steam traps in 1 minute were collected and quantity measured.

(iv) Total amount of condensate& corresponding savingswere then calculated& found as:

Table-7

Recovery/Savings	1 Month	1 Year	Monetray Benefits
	savings	**savings**	**Annually**
Total LP Condensate	86.40	1036.8	
Total MP+ HP Condensate	108.00	1296	
Total Flash steam from MP+ HP Condensate	19.3104	231.7248	287570.4768
Net Total Condensate	175.09	2101.0752	67696.64294
Energy saved from 2101.0752 T Condensate	10395069.55	124740834.6	307269.0486
Total Money saved			**662536.1684**

Also, finally savings from STG condensate routing to CPP De-aerator = 6959520.00 rupees/year

Highlights of Calculation part annually (in one year)

- Total HP&MP Condensate recovered per annum pprox.. = 1296.0 T
- Total Flash steam recovered from the 1296.0 T condensate= 231.72 T
- Total Benefits from the 231.72 T Flash steam
- = 231.72 T *1241.00 rupees/T annually (@Steam cost of 1241.00 rupees/T)
  = 287564.52rupees/per annum ---- (a)
- Total LP Steam Condensate = 1036.8 T
- Total Condensate = 1036.8 + (1296.00-231.72)
  = 2101.075 T
- Total Benefits from 2101.08 T Condensate = 2101.075 T * 32.22 rupees/T (@ DMW cost of 32.22Rupees/T)
  = 67696.642 rupees/annum ----(b)
- Heat Content in 2101.075 T Condensate= 188.75– 129.38= 59.37 kCal/kg
  = 59.37kCal/kg*(2101.075 T *1000kg)
  = 124740822.8kCal
- So, equivalent LP steam in 124740822.8 kCal= 124740822.8 kCal /503.804 kCal/kg
  = 247597.92 kg = 247.598 T of LP steam
- So, Total savings from 247.598 T LP steam = 247.598 T *1241.00 rupees/T
  = 307269.0194rupees/annum ----I
- Additional savings from STG Condensate routing to CPP De-aerator Tank.

Earlier STG condensate was sent to De-mineralized (DM) Water Tank.

Now this STG Condensate (average flow = 25 TPH) would be sent directly to De-aerator Tank. So, there would be a net decrease in DM water consumption of 25 TPH.

So, savings from STG Condensate routing to Condensate Tank
= Total Flow per year * Cost of DM water
= (25*24*30*12) TPY * 32.22 Rupees/T
= 6959520.00 rupees/year ---- (d)

- Thus, total monetary savings = (a)+(b)+(c)+(d)= 76,22,050.176 rupees/year = **76.22 lakh/annum**.

Some Pictures Of High Concentrated Steam Traps Areas inside CGP Battery Limit

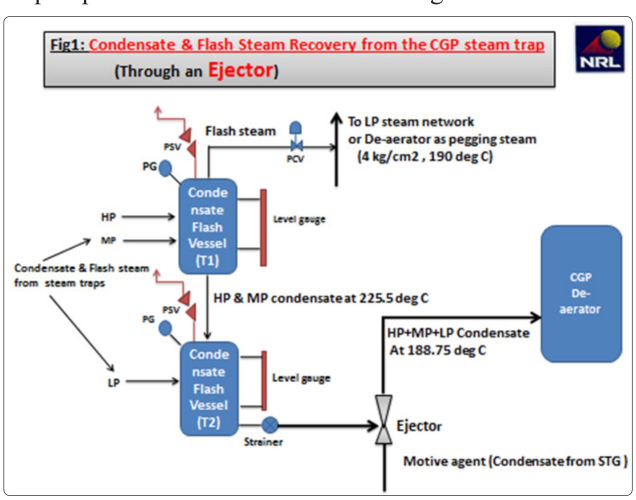
Picture 1: Area between UB & STG Pic-2: PRDS area

Scheme for Condensate & Flash Steam Recovery in CGP (Through an Ejector)

The Condensate &Flash steam are collected in a Condensate Flash Vessel.For, HP & LP condensate and flash steam are collected in Condensate Flash Vessel or Tank (Tank-1). The lower pressure flash steam recovered from the HP & MP Tank-1 is then routed to the LP steam network (4ksc/cm2 and 190 deg C) or to De-aerator as pegging steam through a PCV.

Then only the condensate portion of the Tank-1 goes into the second Condensate Flash Vessel/Tank (Tank-2) where this condensate is together collected with the condensate and flash steam from all the LP header steam traps.

Finally, the HP, MP& LP condensate is routed into the CPP De-aerator through an Ejector where condensate itself (from STG Condensate) is used as the Motive agent for the Ejector. Thus here there is no use of Electric powered motor pump. We have just simply used the help of an Ejector to transfer the condensate without any use of pump.This scheme is illustrated in Fig.1.



In the present era where the importance lies in the conservation andefficient use of Energy, the recovery of both flash steam and condensate would prove to be befitting measures. The recovery would ensure 100% re-use of both steam and water thus leading to zero loss.

Scheme-5
Modification in the CGP BFW system as a means for "Increased efficiency of operation and energy saving"

Wonders of a pressure control valve and a shut-off valve in CGP Boiler Feed Water System
Introduction

A study was carried out on the topic "Refinery Boiler Feed Water (BFW) consumption/demand" & a scheme was developed to conserve energy & optimization of capacity utilization of the existing equipments. The scheme explains the wonders that could be achieved by minimum simple modification with the help of installation of just only of two nos. of valves – a **pressure control valve** (PCV) and a **shut-off/down valve** (SDV). These two valves would help to reduce the 4 nos. of running BFW pumps High Tension (HT) motors to only two nos. In the process, leading to total energy savings of **2933337.24 KWHr** annually and corresponding monetary benefit of **100,32,013.354 rupees** annually. In addition to energy saving, they would bring a lot of flexibility, redundancy and reliability in the CGP BFW system.

In Co-Generation Plant (CGP), there are total 10 nos. of Boiler feed water (BFW) pumps – (2Refinery BFW + 2UB+6HRSG) to meet the internal (own CGP requirement) and the external (Refinery process units) BFW demand.

The present scenario of BFW, both high pressure (HP) & low pressure (LP) demand by the different units of the Refinery from CGP unit are as follows

Table 1

Low pressure(LP) BFW consumption	
Unit	Avg. Consumption
	TPH
CDU/VDU	5
DCU	5
HCU	45
SRB	1
CCU	12
Total	**68**
NB. Low pr. = 35-40 ksc (avg.)	

Table 2

Low pressure(LP) BFW consumption	
Unit	Avg. Consumption
	TPH
UB	30
HRSG	65
MSP	10
Total	**105**
NB. High pr. = 60-65 ksc (avg.)	

NB. For Motor Spirit Plant (MSP), BFW tapping is from the HRSG discharge header.

At present, total LP BFW demand or consumption by the different units of the Refinery is 68 TPH. This LP BFW is supplied through the 2 nos. of Refinery BFW HT motor pumps (1Running + 1Stand-By).

Total HP BFW demand is 105 TPH. The total HP BFW demand is supplied through 2 nos. of Heat Recovery Steam Generator (HRSG) BFW pumps (for HRSG & MSP) and that of Utility Boiler (UB) is separately through its own BFW pumps. There is inter-connection between the UB and HRSG HP BFW headers.

Existing Scheme/System (Pre-Modification Scenario)

1. UB & HRSG HP BFW header interconnection remains in isolated state.
2. HP BFW header & LP BFW header are separate, no inter-connection between them.

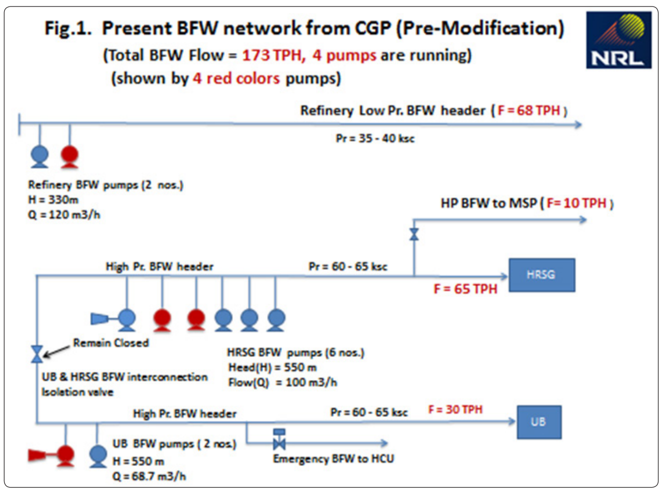


Fig.1. Present BFW network from CGP (Pre-Modification) (Total BFW Flow = 173 TPH, 4 pumps are running) (shown by 4 red colors pumps)

Disadvantages of the Existing Scheme/System

1. Less Flexibility of the Hrsg & Ub Bfw Pumps

As per the present CGP SOP philosophy, during power failure or black out, the UB BFW (turbine) pump must supply BFW to UB for at-least 15 to 20 min. as required by UB for generating emergency steam. During power failure, the UB (turbine) pump cannot sustain for 15 to 20 min. & trips on overload if the inter-connection is kept opened. Hence the HRSG & UB BFW inter-connection is kept closed. Thus the flexibility and redundancy of the available BFW pumps is reduced though there is provision for the inter-changeability of the BFW pumps.

2. Less utilization of HRSG BFW (turbine) driven pump

The more capacity HRSG BFW (turbine) pump in comparison to UB BFW (turbine) pump is kept idle for most of the time. It cannot be put into service as the HRSG & UB BFW header inter-connection is kept isolated.

3. Emergency steam not available if UB BFW (Turbine) is under maintenance

When UB BFW (Turbine) is under maintenance, then the emergency steam from UB is not available. This problem could not have arisen if HRSG BFW (turbine) could be put into service.

4. Critical condition of Refinery Low Pressure (LP) BFW

(i) At present, one Refinery LP BFW is in service and the other pump remains stand by. If the stand by pump is under maintenance and the running pump also develops some problem, then the condition becomes critical as there is no 3rd pump or any other means to meet the Refinery LP BFW demand. So the downstream Refinery Units may get hampered.

(ii) In future, both the pumps have to be run to meet the increasing BFW demand of the Refinery. So there would be no stand by pumps i.e., no redundancy.

Post Modification Scenario for new schemes (pictures shown below)

1. Installation of one "BFW shut-off valve or Shut down valve - SDV" in HRSG BFW header

This valve will close on Auto immediately on both partial and total power failure and divert the whole BFW flow only towards UB. This may be in auto or key operated Shut-off valve.

2. Provision for inter-connection between HP and LP BFW via one "BFW pressure control valve– PCV"

The control valve would reduce the HP BFW pr. (avg. 60-65 ksc) to LP BFW (avg. pr. = 35-40 ksc). Thus HP BFW header could be used as LP BFW.

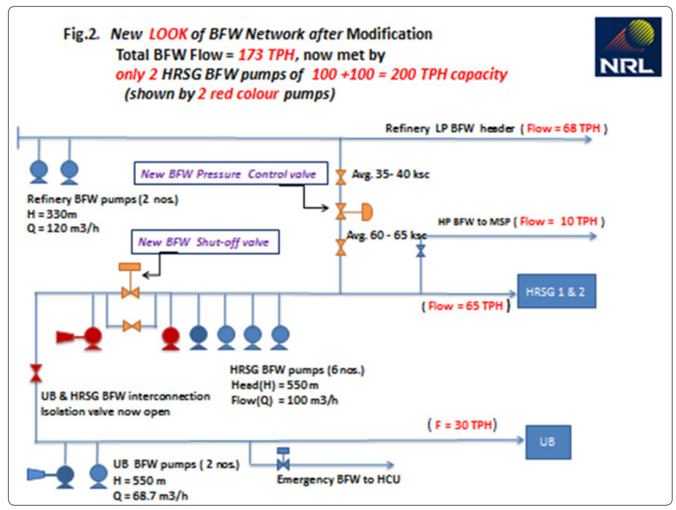


Fig.2. New LOOK of BFW Network after Modification Total BFW Flow = 173 TPH, now met by only 2 HRSG BFW pumps of 100 +100 = 200 TPH capacity (shown by 2 red colour pumps)

Advantages of the new schemes

1. More flexibility and redundancy of UB & HRSG BFW pumps

Now combination of any UB and HRSG pumps could be put into service provided one turbine pump is in service. Thus total 8 nos. (2UB+6HRSG) of pumps are available for both UB and HRSG. Thus flexibility and redundancy is increased manifold. The stand-by pumps would be kept in Auto mode to care of any pressure fluctuation in the BFW network.

2. Energy conservation & reduction in emission of Greenhouse gases

(i) In the earlier system, one UB (Turbine) pump & 2 HRSG HT motor BFW pumps were in service with the inter-connection between them in isolated/closed condition. In the new scheme, the UB (turbine) pump could now be replaced by a more capacity HRSG (Turbine) pump as the inter-connection is now opened. The total HP BFW demand could now be met by only two nos. of HRSG BFW pumps. Thus combination of 2 nos. of HRSG pumps (one turbine + one motor) would be sufficient, i.e., from earlier combination of two HRSG HT motor driven pumps , one HT motor would be replaced by one turbine and one HT motor pump. This leads to energy saving by stopping one HT motor pump.

(ii) Also total BFW demand of the Refinery could be met by the two nos. of HRSG BFW pumps.
Total BFW demand = 178 TPH, and designed capacity of the HRSG BFW pump is 100 TPH each. So two pumps would give 200.0 TPH. Thus another HT Refinery BFW pump could be stopped leading to further energy conservation & corresponding Greenhouse Gas emission which would have been released on burning that amount of equivalent fossil fuel.

(iii) Total energy or fuel saved = **2933337.24 KWHr** annually
Total fossil fuel saved = **44157.994 MT** (Naphtha) or **40437.723 MT** (NG) annually
Total monetary benefit = **100, 32,013.354 rupees annually**.

3. Emergency steam is not hampered

As now both UB and HRSG (turbine-T) pumps are inter-changeable, hence anyone could be in service and the other as stand by. Emergency steam would be available all the time.

4. More flexibility between HP and LP BFW headers

With the new scheme, the HP BFW could be converted into LP BFW through a control valve. Thus for Refinery LP BFW, there are total 10 nos. pumps (2 Refinery BFW + 2UB + 6HRSG pumps). So now there is no criticality if both the Refinery BFW pumps are under maintenance.

5. Meet future demand of HP or LP BFW easily

Now, total HP BFW pumps = 8 nos. (2UB +6HRSG); LP BFW pumps = 10 nos. Any increase in Refinery HP or LP BFW demand could be met easily as the nos. of availability of pumps is increased manifold.

6. Better emergency handling

In the new scheme, the BFW shut-off valve immediately cut-off the BFW supply to HRSG, MSP and Refinery BFW header, and diverts the BFW to only UB. This reduces the manual intervention of isolating the BFW network during emergency.

(i) Cost/Money saved on stopping one HRSG HT motor pump:

In one day, total power saving = (sqrt3*V*I*cos phi)* running hours
= (1.732*6.6 kV* 19 A*0.9) * 24 hrs
= 4,691.364 kW hrs per day

In one month, total power saving = 4691.364*30
= 1,40,740.92 kW hrs per month

In one year, total **power saving** = 140740.92 *12
= 16, 88,891.04 kW hrs per year

So, total **cost saving** in one year = Total power * rate
= 16, 88,891.04 kW hrs per year * Rs. 3.42
(Unit power cost = Rs 3.42) = 5776007.35 rupees annually.

To produce 16, 88,891.04 kW hrs per year energy **22125.413 MT** per year of **Naphtha** or **20261.367 MT** per year equivalent of **NG** would have been burnt in a year.

(ii) Cost saving on stopping one HT Refinery BFW motor pump

In one day, total power saving = (sqrt3*V*I*cos phi)* running hours = (1.732*6.6 kV* 14 A*0.9) * 24 hrs = 3456.795 kW hrs per day

In one month, total power saving = 3456.795 *30
= 103703.85 kW hrs per month

In one year, total **power saving** = 103703.85 *12
= 1244446.20 kW hrs per year

So, total **cost saving** in one year = Total power * rate = 1244446.20 kW hrs per year * Rs. 3.42 (Unit power cost = Rs 3.42) = 4256006.004 **rupees annually**.

To produce 16, 88,891.04 kW hrs per year energy **22032.581 MT** per year of **Naphtha** or **20176.356 MT** per year equivalent of **NG** would have been burnt in a year.

Thus the total annual savings are

Total energy or fuel saved = 2933337.24 KWHr.
Total fossil fuel saved = 44157.994 MT (Naphtha) or 40437.723 MT (NG).
Total monetary benefit = 100, 32,013.354 rupees.

Reduction in CO_2 emission (NG)
2933337.24 kWh Energy saved annually
NG emits 0.502 kg of CO_2 per kWh
So, **1472.535 T** of CO_2 emissions would be reduced annually.

So with the help of just two valves- one PCV and one SDV on the BFW network, a wonderful thing could be achieved. They have thus led to ***"Increased efficiency of operation and energy saving"***

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Scheme-6
Huge Green Energy Recovery at No Extra Cost through Ng Turbo-Expanders

This scheme brings into Reliability, Redundancy & Flexibility during Refinery Total Power failure of our Refinery - A Complete Package for quick and safe start-up of Co-Generation Plant after blackout and emergency conditions with minimum manpower. In this process, apart from providing solutions to the problems and short comes, there is a huge potential of Green Energy recovery through Natural Gas (NG) Turbo Expanders without burning any extra fossil fuels.

In NRL, there are two nos. of Gas Turbines (GTG-01 and GTG-02) & one Steam Turbine Generator (STG) in CGP and to meet refinery power demand, one GTG & STG are operated. Both turbines are originally rated 30 MW but they have been uprated a couple of years ago and expected to yield 34 MW. Each GTG has downstream Heat Recovery Steam Generators (HRSG) of capacity 130 TPH (with supplementary firing) which recovers heat from the Gas turbine hot exhaust flue gases.

Normally we operate one GTG along with HRSG (cogeneration mode) and STG to meet power demand (average 34 MW). During non-availability of STG, the other GTG is put in service in simple cycle mode. Normally one GTG is kept on standby.

We have some problems, short comes and some issues during total power failure and its start up process. We have studied these problems and discovered that there were scopes of improvements. In the process, we have innovated new measures to tackle them so that the emergency situation during total power failure could be handled smoothly with safety, quickly and minimum manpower.

Problems Faced With the Present Conditions (No Grid Power Hook Up For Back Up On Total Power Failure, So Total Power Failure Is Inevitable When both the Running GTG and STG Trip)

1. Presently on Total Power failure and blackout condition, cooling circuit also gets interrupted and cut-off. This leads to draining of GTG cooling circuit. There is **no provision to hold up back that Cooling Water (CW) of GTG circuit** until we close the CWS/R valves of GTG manually. Due to this available local CT of GTG gets over loaded. The local CW already hold up volume of CW is not sufficient to supply sufficient CW for the restart of GTG and it's auxiliaries. If there would have been a provision of instant stopping of CWS/R valves of GTG immediately on power failure, then local Cooling Tower (CT) would be easily used to safely start GTG from blackout conditions. So to restart the GTG from the blackout condition, **major problem faced is the line-up and supply of CW to GTG** and it's auxiliaries up-to Full Speed no Load (FSNL) and synchronization with the dead bus. After that on restoration of electrical power, CT cooling water pump is started one by one and CW circuit is normalized.

   Present start up procedure includes line up of DM water feed header at CPP Battery Limit as CW source which is cumbersome, involves more manpower, needs precise adjustment of hook up valves DM & CW. Also there is a chance of **tripping of DM feed pump**. Sometimes we need to run two nos. of DM water feed pump also which sometimes overloads the Black Start Diesel Generator (BSDG) / Emergency Diesel Generator (EMDG) of CPP.

2. Secondly, **BSDG/EMDG and 500 kVA DGs gets overloaded** on blackout conditions and **trips**.

3. Thirdly, GTG Liquid & Natural Gas (NG) fuels shut-off and vent valves are operated by Instrument air (IA) supplied by Low Pressure (LP) compressor. So GTG is dependent on the availability of LP compressor. If LP compressor fails/trips, then this would also lead to total power failure and blackout conditions. Also, during re-start we need to **open the NG fuel header main shut-off valves FG-11 valve and close the vent valve VG-11 manually** as there is **no IA in blackout conditions**. This involves another extra manpower during emergency conditions. Also during normal running conditions, if LP compressor trips and stand-by LP compressor could not be started in time, then running GTG and STG would also trip and lead to Total Power Failure or Blackout conditions.

4. Fourthly, **Utility Boiler (UB) fuel control valves, vent valves and shut-off valves are also dependent** on the availability of LP compressor as they are too **Instrument air** operated. Though they are having back up of IA from High Pressure (HP) receiver, sometimes it is observed that control valves and shut-off valves get closed earlier than as expected for pprox. 20 minutes so that UB could not supply HP steam for that 20 minutes which is required for the safe shutdown of the different Refinery units. Also during normal running conditions, if LP compressor trips and stand-by LP compressor could not be started in time, then UB would trip and lead to an emergency situations. So **reliability and availability of Emergency steam from UB is not 100% ensured**.

Solutions to All the Above Problems

1. (i) Solution to 1st problem is **installation of two quick shut-off valves on GTG CWS/R headers** to hold back the CW in the whole GTG circuit intact just after total power failure. In addition to that, one **NRV may be installed** in the CWR header as an extra source of reliability. In this condition, local GTG CT pump WC and local cooling fans FC-1/2/3 could be used to start the GTG and reach up-to FSNL and synchronization with dead bus. There is an expansion tank for back up of additional supply of CW or any loss of CW in that scenario. Also as a final back up if we **supply power** of BSDG/EMDG to lower motor rating capacity **Service Water (SW) pump** (30 kW, 140 m3/h, 4.4 kg/cm^2) instead of higher capacity DM water feed pump (75 kW, 220 m3/h,6.7 kg/cm^2) at RWTP. Due to this, there **is a less chance of tripping of BSDG/EMDG**. So, isolation of GTG CWS/R would be done in Auto (manual open/close Push Button from control room DCS system may also be available) and there is no requirement of extra manpower. Also now there is no requirement of extra manpower in line up of DM feed and CPP CWS/R headers change-over at CPP Battery. So manpower requirement is reduced.

Fig.1- Existing CWS & CWR circuits for GTG1 & GTG2 (Pre-Modification)

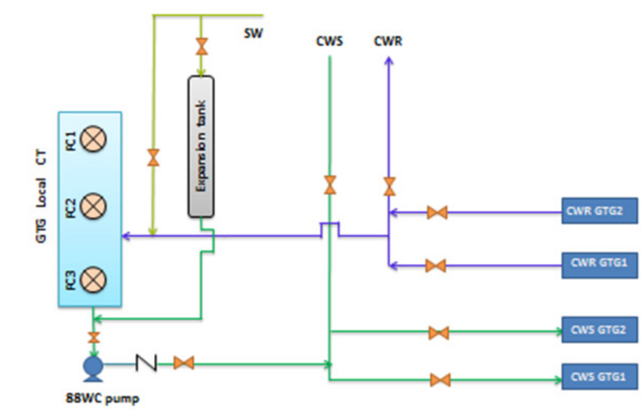
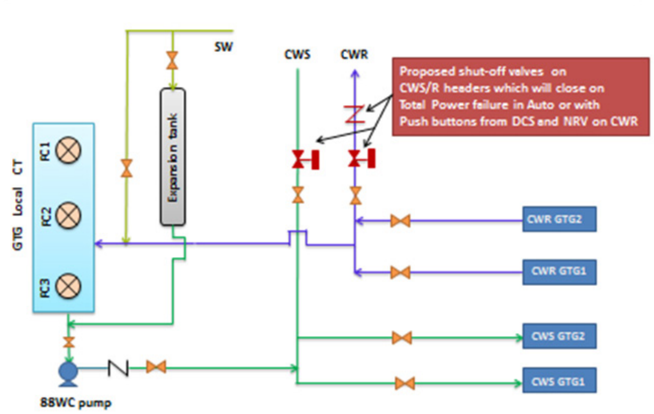


Fig.2- Modified CWS & CWR circuits for GTG1 & GTG2 (Post-modification)



2. Partial solution to the 2nd problem is mentioned in the above solution-1. Also in addition to that we shall **install NG Turbo-Expander-Generators** in parallel to the existing NG Pressure Control Valves (PCVs) at 3 locations to recover lost mechanical energy in PCVs and convert it into useful electrical power energy through the expanders. During normal running conditions, they would be producing electrical power through normal NG flow. During total power failure or blackout conditions, they too would generate Electrical power by taking NG inlet at same pressures and flow and giving discharge to the flaring system until normalization of the NG consumption by the Refinery units.[When they are under maintenance, PCV would be in line]. There would be a **Huge Green Energy Recovery at no Extra Cost**.

(i) 1st NG Turbo-Expander-Generator at Duliajan Numaligarh Pipeline (DNPL) NG receiving station at Numaligarh Refinery Limited (NRL).

- Here PCV reduces NG pressure from 40 ksc into 32 ksc; (ksc– kg/cm^2).
- Maximum NG flow = 40 TPH
- Minimum NG Flow = 15 TPH
- If NG Turbo-Expander-Generator is installed in parallel to this NG PCV, then
- We would get pprox.. Minimum Power = 1687.65 kWh(Pmin)
- Max Power = 4500.41 kWh (Pmax)
- NG temperature at Expander outlet = **20.86 deg C** (T2)

(ii) 2nd NG Turbo-Expander-Generator at NRL NG KOD area

- Here PCV reduces NG pressure from 31 ksc into 4 ksc.
- Maximum NG flow = 7 TPH
- Minimum NG flow = 5 TPH
- If NG Turbo-Expander-Generator is installed in parallel to this NG PCV, then
- We would get pprox.. Minimum Power = **769.33 kWh**(Pmin)
- Max Power = **1077.06 kWh** (Pmax)
- But here, we may have one issue. The outlet NG Temperature after expansion would be in the negative side (-73.68 deg C = T2). To solve this issue, there are two probable solutions:
- **1st Solution: Reduce pressure ratio** to **31:22** from 31:4, then NG temperature at Expander outlet would be **13.5 deg C**, after this NG **pressure would be reduced to 4 ksc by PCV** ; or else
- **2nd Solution: Install pre-heater** and increase NG inlet Temperature to about 160 deg C, then NG temperature at Expander outlet would be **7.17 deg C**
- **1st Solution would be feasible.**

(iii) **3rd NG Turbo-Expander-Generator** at NRL GTG NG conditioning skid

- Here PCV reduces NG pressure from 31 ksc into 22 ksc.
- Maximum NG flow = 9.7 TPH
- Minimum NG flow = 2.433 TPH
- If NG Turbo-Expander-Generator is installed in parallel to this NG PCV, then
- We would get pprox.. Minimum Power = **301.135 kWh**(Pmin)
- Maximum Power = **1200.578 kWh**(Pmax)
- NG temperature at Expander outlet = **18.114 deg C** (T2)

(iv) So, through 3 nos. of NG Turbo-Expander-Generators, we would have:

- Total Pmin = **2758.51 kWH**
- Total Pmax = **6778.051 kWh**

(v) Thus net total power in blackout conditions = EMDG+NG Turbo-Expander-Generator
= 600 kWh + 2758.51 kWh = **3358.12 kWh** (minimum power); **Thus Huge Green Energy at No Extra Cost …….**

(vi) So this would boost up the power availability and **completely eradicates the problem of EMDG & 500 kVA DGs overloading** and help us in the **smooth start-up from the total power failure and blackout conditions**.

Fig.1- Existing NRL NG distribution network (Pre-modification)

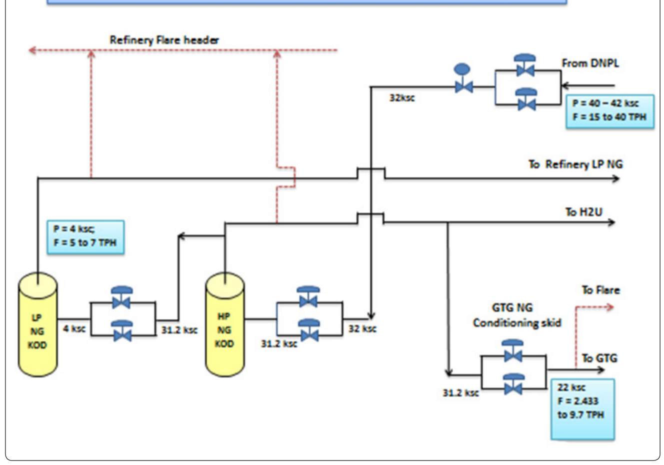
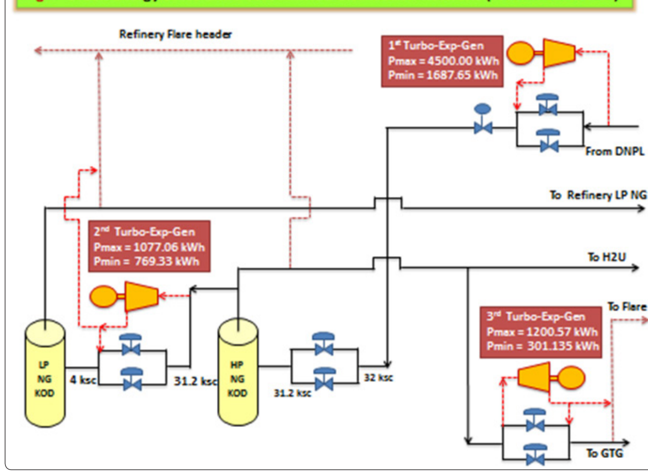


Fig.2- Green Energy at No Extra Cost ……. NG distribution network (Post-modification)



3. Solution to the 3rd problem **is replacing Instrument Air (IA) by Nitrogen gas** (N2) as a media for operating GTG Liquid & NG fuels shut-off and vent valves. Also there would separate N2 accumulator cylinders as a back-up source of N2 gas for operating the valves. This would bring reliability and ensures availability of working media of N2 all the time. Also **even in the blackout conditions when total power is cut-off, N2 gas would be immediately supplied from the Liquid N2 storage tank** in addition to the accumulator back-up. **[In comparison to IA, N2 gas is much more pure, lesser chance of moisture present and inert in nature**; which makes **N2 a better and more reliable source than IA**. N2 pressure would be sufficient for the operation of the valves as it remains in the range of 4 to 5 ksc and to operate the valves, a pressure of 4 ksc is required].

4. Similar to the 3rd one, UB **fuel control valves, vent valves and shut-off valves** would also be operated by **N2 gas instead of IA**. This would ensure that even in blackout conditions, fuel control valves would be operated without any problem and thus UB could run easily for the stipulated time of about 20 minutes.
5. For an extra added safety, the **Fuel SOVs and it's accessories** would be installed **and placed at a safe distance** from the main fuel header (Naphtha, HSD & NG) to **protect from any fire hazards** that may arise between any electric spark of the electric cables & SOVs current signals (due to cable damage, looseness, malfunctions, short circuit, etc.) and any leakage of the fuel source.

Advantages of the above schemes

- Safe shutdown of GTG, UB & other Refinery units during Total Power failure.
- Reliability in the supply of emergency steam by UB for the stipulated time of pprox.. 20 minutes.
- Reliability and bring into confidence in the availability of Power and Cooling water during Total Power failure/blackout conditions.
- Completely eradicates the problem of EMDG & 500 kVA DGs overloading during total power failure.
- Quick and safe start-up of GTG after blackout and emergency conditions.
- Minimum manpower involvement as no line up of DM feed as CWS/R (which involves 3 to 4 persons to operate 4 nos. of big valves at CPP B/L, no manual interpretation in GTG FG-11 & VG-11 valves.
- Utilization of huge Mechanical Energy and converting into Electrical Energy (Power) that was lost in NG PCVs by the help of Turbo-Expander-Generators. So savings in fossil fuels and thereby reduction in emission of harmful greenhouse gas CO2 into the atmosphere, so contributing in making the environment greener.
- Now GTG & UB is independent of LP compressor IA supply. So if there would be an emergency in the LP compressor end, there is no such worry situation in the GTG & UB sides.
- Better performance & reliability of NG fuel control valves and shut-off valves, very lesser chance of corrosion & malfunction due to use of N2 as media to operate them.
- Safer from the fire hazards due to use of N2 and shifting the Fuel SOVs and it's accessories to a safe distance from the fuel sources.

Details of Calculations & Formulae Used

(i) Power Generated by the NG Turbo Expander

$$Hs = ZRT1\left(\frac{k}{k-1}\right)\left(1-\frac{p2}{p1}\right)^{1-\frac{1}{k}} \quad \text{Equation-1}$$

$$P = Hs * m * ys \quad \text{Equation-2}$$

$$T2 = T1\left(\frac{p2}{p1}\right)^{1-\frac{1}{k}} \quad \text{Equation-3}$$

Isentropic head (Hs) developed in the NG Turbo Expander is calculated by the above **equation 1**,
Electrical Power (P) generated by the **equation-2**, and
NG temperature (T2) at the Expander outlet by the **equation-3**;

Where:

- **Z** = Compressibility Factor of NG = **0.92675**
- **R** = Individual Gas Constant of NG = Cp - Cv = (2.35 -1.85) kJ/kgK = **0.5 kJ/kgK**
- **T1** = NG Temperature at Expander inlet (deg Kelvin, K)
- **k** = ratio of Specific Heat=(Cp/Cv) = 2.35/1.85 = **1.27**
- **p1** = NG Pressureat Expander inlet (ksc)
- **p2** = NG Pressureat Expander inlet (ksc)
- **m** = NG mass flow rate (kg/s)

(ii) Electrical Power Generation & NG outlet temperature at expander outlet in all the 3 cases is found as

Case 1: At NRL NG Receiving Station

p1 (inlet Pressure)	40	KSC
p2 (outlet pressure)	32	KSC
Fmax	40	TPH
Fmin	15	TPH
T1	35	308.15 K
Hs	476.5139	

Outlet Temp
293.8617228 K
20.86172279 C

By, putting all the above values in formulae we get:

P(max)	4500.409	kWhr
P(min)	1687.654	kWhr

Case 2: At NRL NG KOD (HP to LP)

p1 (inlet Pressure)	31	KSC
C Cp2 (outlet pressure)	4	KSC
Fmax	7	TPH
Fmin	5	TPH
T1	35	308.15 K
Hs	651.669	

Outlet Temp
199.319158 K
-73.680842 C

By, putting all the above values in formulae, we get:

P(max)	1077.064166	kWhr
P(min)	769.331547	kWhr

Case 3: At NRL NG GTG Conditioning Skid

p1 (inlet Pressure)	31	KSC
p2 (outlet pressure)	22	KSC
Fmax	9.7	TPH
Fmin	2.433	TPH
T1	40	308.15 K
Hs	524.206	

Outlet Temp
291.1141158 K
18.11411575 C

By, putting all the above values in formulae, we get:

P(max)	1077.064166	kWhr
P(min)	769.331547	kWhr

So, net Total Electrical Power generated by all the 3 nos. of **NG Turbo-Expander-Generator** is:

Total P(max)	**6778.051**	kWhr
Total P(min)	**2758.120**	kWhr

Projected Savings through the schemes:

Per Day Saving (min)	**2,26,386.47**	rupees
Per Month Saving (min)	**67,91,594.00**	rupees
Per Year saving (min)	**8,14,99,128.02**	rupees

Per Day Saving (max)	**5,56,342.47**	rupees
Per Month Saving (max)	**1,66,90,274.00**	rupees
Per Year saving (max)	**20,02,83,287.97**	rupees

(@ Cost per kWh = 3.42 rupees)

Thus net total power that would be in blackout conditions (after GTG and STG Tripping):
= EMDG+NG Turbo-Expander-Generator
= 600 kWh + 2758.51 kWh = **3358.120 kWh** (minimum power).
= 600 kWh + 6778.05 kWh = **7378.051 kWh** (maximum power).

Conclusion

(i) 1st Feature

- No more blackout conditions. Minimum Power of 3358.12 kWh would be available even after the tripping of the running GTG and STG.
- GTG & UB (NG fuel auxiliaries) are now independent of Instrument Air supply from LP compressor. So, emergency of IA shortage is no longer an issue.
- GTG could be re-started quickly and safely with the own existing facility with minimum modification and minimum investment.
- Minimum manpower involvements in the GTG re-start up process.
- Brings into Reliability, Redundancy, Flexibility and Confidence in the Operation of CPP.

(iii) 2nd Feature

- Discovery and utilization of huge untapped potential of lost energy in the 3 PCVs by installing 3 nos. of NG **Turbo-Expander-Generator** in parallel to them.
- **Green Energy** - Power Generation at No Extra running/ operating cost
- Reduction in GTG load.
- Reduction fossil fuel consumption and overall specific energy consumption of the Refinery.
- Reduction in emission of greenhouse gases (CO_2) and thus contributes towards an Eco-Friendly Environment (one of the means to reduce air pollution).

Reduction in CO_2 emission (NG)		
NG emits 0.502 kg of CO_2 per kWh		
So, CO_2 reduced (min)	1384.5761	kg/h
	33229.8264	kg/day
	11962737.5	kg/year
	11962.7375	Tonne/year
CO_2 reduced (max)	3402.58185	kg/h
	81661.96439	kg/day
	29398307.18	kg/year
	29398.30718	Tonne/year

(iv) 3rd Feature

- Easy to set up.
- Only initial set up cost. No more running cost. Power generated at the expense of Energy recovered which otherwise was lost in the existing PCVs.

Conclusion

It has been discovered that there is a substantial energy saving potentials in all the schemes mentioned above. Effective and efficient use of energy by minimizing all loses is very much important in a grass root refinery like NRL considering its geographic location. Energy conservation not only save precious fossil fuel like coal, gas, oil, etc., but also leads to reduction of emission of harmful greenhouse gasses. Thus the energy efficiency & conservation also plays a vital role in contributing towards greener & better environment to live in. Energy is the main driving force of economic growth of a country. Tomorrow's economic growth depends upon today's efficient & effective use of energy. Hence, energy conservation & the practical application & creating awareness of energy efficient methods are very much essential for the sustenance & development of a modern economy of the country. Thus the above Innovative & In-house Energy Saving Schemes in NRL Co-Generation Plant prove to be befitting solutions towards the sustenance and growth in this era where there is an increasing gap between the ever rising demand & the limited supply of energy.

Abbreviations used:

- NRL – Numaligarh Refinery Limited
- CGP – Co-generation Plant
- CPP – Captive Power Plant
- CDU/VDU – Crude Distillation Unit
- HCU – Hydro-cracker Unit
- MSP – Motor Spirit Plant
- DCU – Delayed Coker Unit
- CCU – Coke-Calcinations Unit
- GTG – Gas Turbine Generator
- STG – Steam Turbine Generator
- HRSG – Heat Recovery Steam Generator
- UB – Utility Boiler
- BFW – Boiler Feed Water
- PCV – Pressure Control Valve
- SDV – Shut-off valve or Shut Down Valve
- SOV – Solenoid Operated Valve
- DM – De-mineralized Water
- SW – Service Water
- CT – Cooling Tower
- CW – Cooling Water

- CWS – Cooling Water Supply
- CWR – Cooling Water Return
- LP – Low Pressure
- MP – Medium Pressure
- HP – High Pressure
- PRDS – Pressure Reducing and De-superheating station
- LPC – Low Pressure Compressor
- NG – Natural Gas
- GCV – Gross Calorific value
- KOD – Knock Out Drum
- IFO – Industrial/Intermittent Fuel Oil
- DG – Diesel Generator
- EMDG – Emergency Diesel Generator
- BSDG – Black Start Diesel Generator
- FSNL – Full Speed No Load
- IA – Instrument Air
- PA – Plant Air
- N2 – Nitrogen
- T – Tonne
- ksc – kg/cm^2
- MT – Metric Tonne
- TPH – Tonne Per Hour
- kW – Kilo watt
- MW – Mega Watt

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