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Review Article

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A New Learning Experience in Gas Turbine Generator a Case Study of Blackout Conditions Due to Tripping of Gtg and the Necessary Corrective Actions to Prevent the Reoccurrence

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Abstract
This paper describes about the case study of a very interesting and peculiar blackout conditions (total power failure) arising out of both the Gas Turbine Generators (Two units of GTG, namely GTG-01 & GTG-02) units back to back tripping in a short span of a week's time. It brings out the various observations noted during that condition and it's root cause analysis. It also highlights the various possible corrective actions in a short term and long term basis to prevent the reoccurrence of such blackout situations.

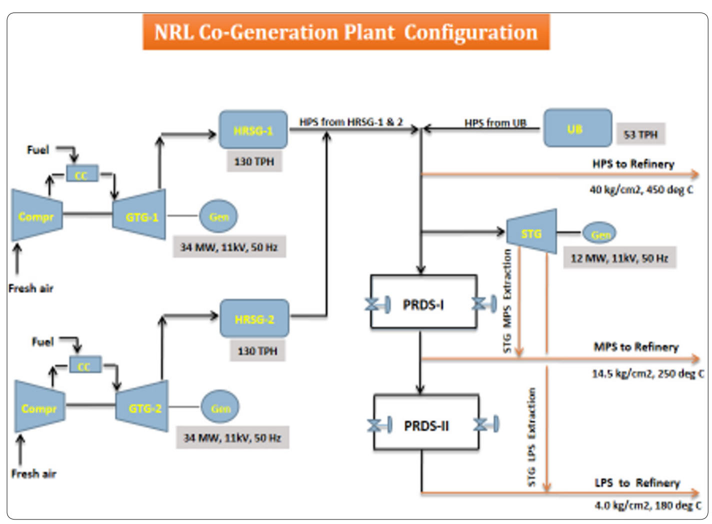
Introduction
In Co-Generation Plant (CGP) or Captive Power Plant (CPP) of Numaligarh Refinery Limited (NRL), there are two nos. Gas Turbines (GTG-01 and GTG-02) along with HRSGs, one Steam Turbine Generator (STG) and one Utility Boiler (UB) in Co-Generation Plant to meet refinery power & steam demand.

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.

In NRL, there are two nos. Gas Turbines (GTG-01 and GTG-02) & one Steam Turbine Generator (STG) in NRL Co-Generation Plant (CGP) and to meet refinery power demand, one GTG & STG are operated. Each GTG has downstream Heat Recovery Steam Generators (HRSG) of capacity 130 Tonne Per Hour (TPH) with supplementary firing which recovers heat from the Gas turbine hot exhaust flue gases to generate High Pressure Superheated Steam (HPS). Both turbines were originally rated 30 MW each; but both GTG-1 in April'2015 and GTG-2 in September'2016 have been up-rated and expected to yield 34 MW each (load testing done successfully up to 30.3 MW for GTG-1 and 31.0 MW for GTG-2). We also have one Utility Boiler (UB) of capacity 53 TPH with four nos. of burners to generate HPS.

One portion of HPS is supplied to the Refinery HPS header network. Another portion of HPS is converted into Medium Pressure Superheated Steam (MPS) through Pressure Reducing and De-superheating Station-I (PRDS-I). This MPS is then supplied to the Refinery MPS header network.

Lastly, one portion of the MPS is further let down into Low Pressure Superheated Steam (LPS) through Pressure Reducing and De-superheating Station-II (PRDS-II). Also from the STG, MPS and LPS are extracted and then supplied to the Refinery MPS & LPS headers respectively.



Case Study

Two very interesting and peculiar incidents and almost the same nature of observations occurred in which running GTG-1 & GTG-2 tripped on 27.06.2018 and 02.07.2018 respectively resulting in the total blackout conditions in the entire Refinery and NRL Township areas.

A Short description of the GTG Tripping Incident:

On 27.06.2018 STG and GTG-1 were running with 6.38 MW and 26.27 MW respectively. During heavy rain and thunder storm STG breaker opened at around **00:50:35.8 hours** without any trip alarm in DCS Max DNA screen. After STG tripping, Intelligent Load Shedding Scheme (ILSS) got actuated leading to a load shedding of 1.21 MW and GTG-1 load increased suddenly to 31.44 MW (as per ILSS record) which lead to suddenly increasing of the Inlet Guide Vane (IGV) opening, Fuel stroke reference and turbine exhaust temperature. During that period, some of the motors of different units of the Refinery were found to be started due to sudden tripping of STG and partial power failure. Simultaneously GTG-2 was also started immediately to compensate the power back up due to STG tripping. The starting of the some of the motors and GTG-2 auxiliary motors further increased the load on the only surviving GTG-1. As a result the IGV opening became maximum (86 deg angle) and it's Exhaust temperature and it's Reference temperature became equal.

Thus the machine went to base load condition and fuel stroke reference (FSR) in Temperature control active mode before reaching it's maximum expected load of 34 MW after uprating and also before the load shedding/capping limit of 31.5 MW. The further extra load due to the start-up of the motors of different units of the Refinery and GTG-2 auxiliary motors further overloaded the machine already in base load condition. But on the other hand, FSR was constantly reducing (as FSR is in Temperature control mode) to decrease and bring down the Turbine exhaust temperature profile under control. Thus on one hand extra load was coming on GTG-1 and on the other hand fuel FSR was on the decreasing trend. This ultimately reduced the Turbine speed constantly and in the process Generator breaker opened on 'Under Frequency" at a speed of about 94.092 RPM (or 47.04 Hertz frequency) and Turbine was unloaded leading to a total blackout conditions in the entire Refinery Units and NRL Township complex.

Exactly similar scenario was observed in the running GTG-2 just after 6 days on 02.07.2018 leading to another total blackout conditions in the entire Refinery and Township in a period of just a week's time.

Root Cause Analysis of both GTGs Tripping:-
Analysis of GTG-1 Tripping:

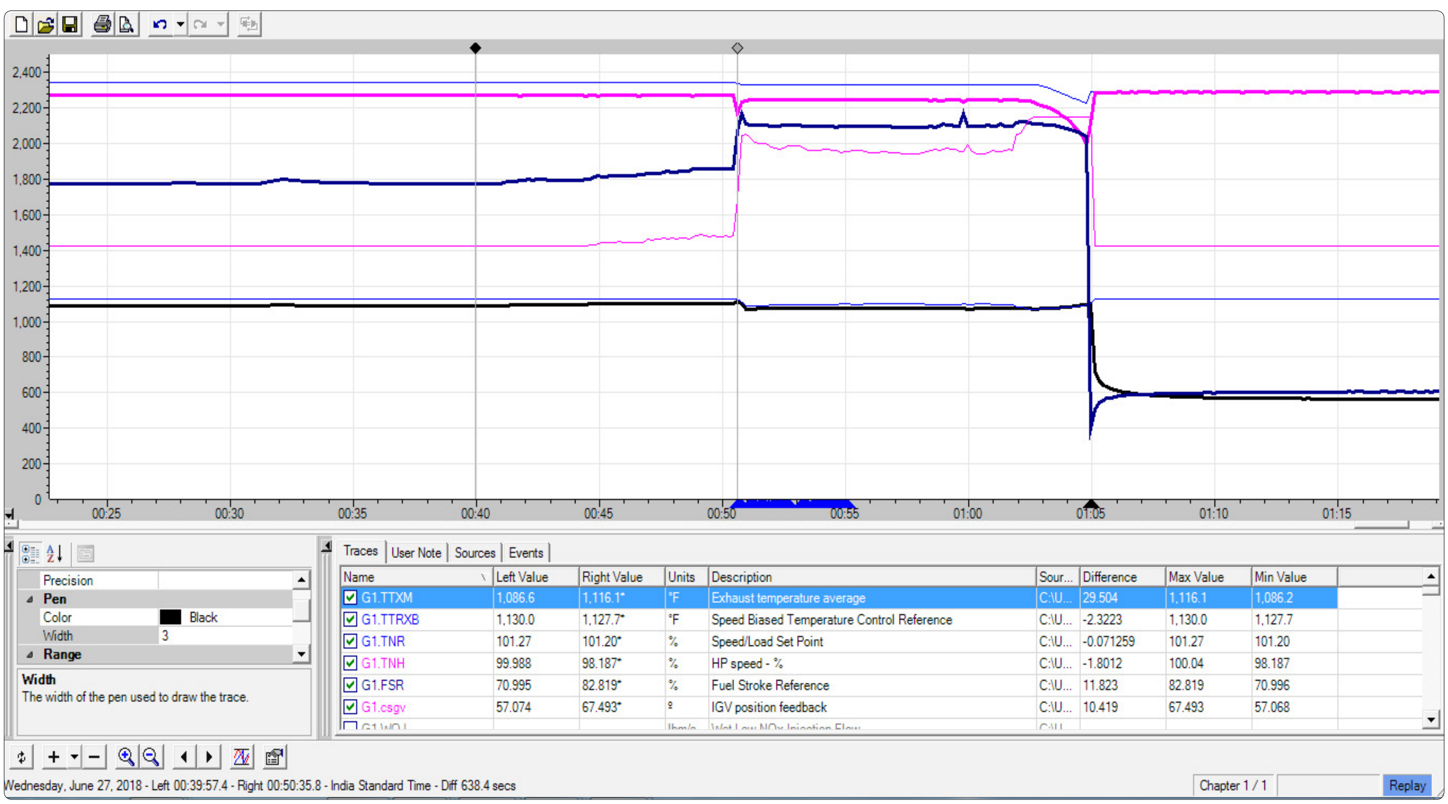


Figure 1: GTG-1 trends before and after tripping.

STG and GTG-1 were running with 6.38 MW and 26.27 MW respectively on 27.06.2018.

At 00:50:35.8 hours, due to tripping of running STG and and subsequent load shedding of 1.21MW, GTG-1 load suddenly increased from 26.27 MW to 31.44 MW. As a result, there was a sudden dip in the Turbine speed (TNH – Thick line in pink colour) from 99.988% to 98.817%. The Fuel Stroke Reference (FSR- thick line in dark blue colour) suddenly increased from 70.995% to 82.819%. Also the Turbine Exhaust temperature (TTXM = 1116.1 deg F; thick line in black colour) started to increase rapidly due to sudden increase in the FSR. And Turbine Exhaust Reference temperature (TTRXM =1127.7 deg F; thin line in light blue colour) started to reduce and tend towards Exhaust Temperature to protect the Turbine from over temperature trip. This resulted in increase of IGV opening (csgv= 67.493 deg angle; thin line in pink colour) to reduce the exhaust temperature profile.

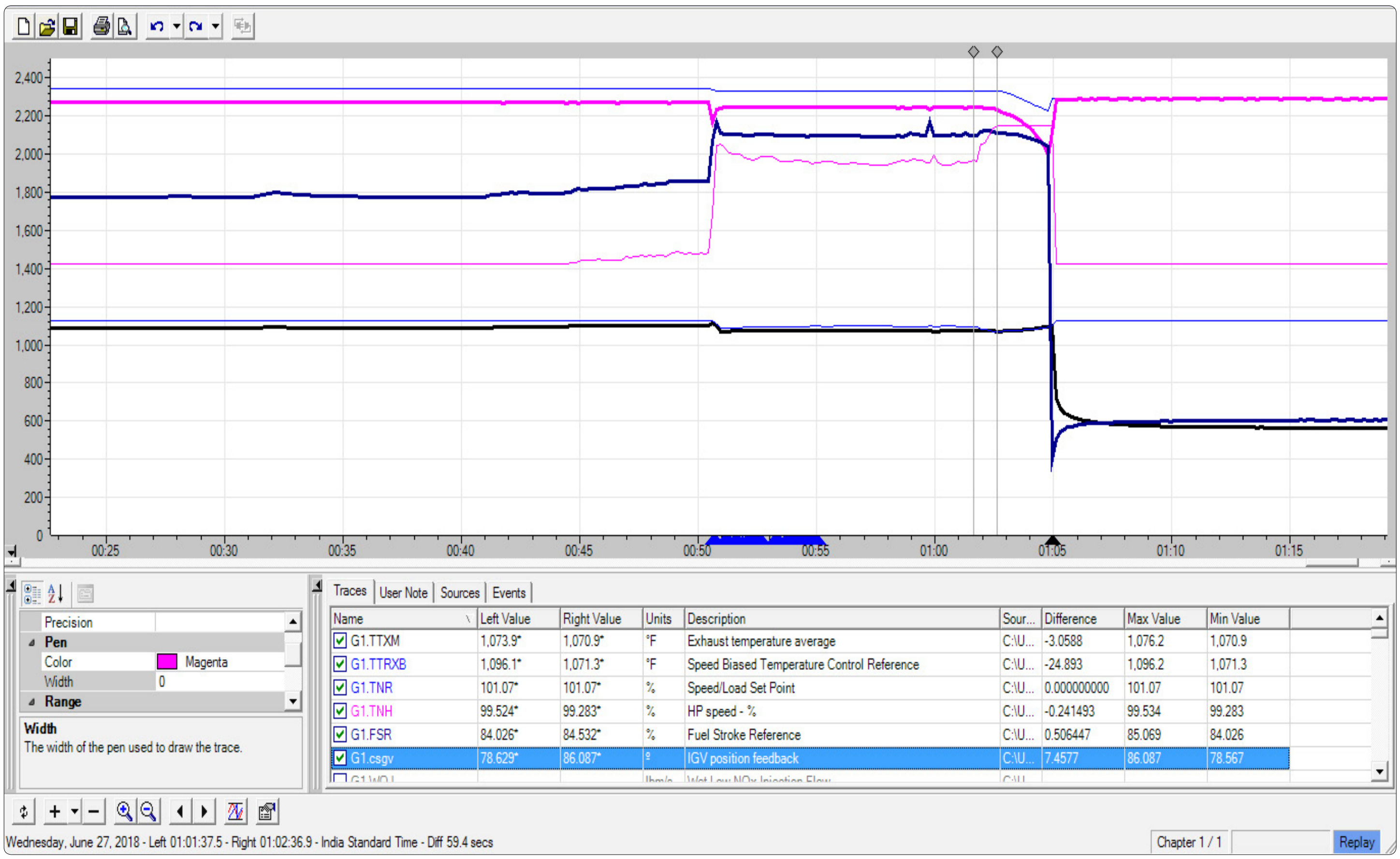


Figure 2: GTG-1 trends before and after tripping.

At 01:02:36.9 hours, the continuous increase in the FSR due to starting of few additional motors of the Refinery Units and start-up of the stand by GTG-2 auxiliaries motors (to sustain high Refinery load and prevent GTG-1 from tripping on overload) further increased the power load of the already loaded GTG-1, This resulted Exhaust temperature (TTXM = 1070.9 deg F) equalling with it's Reference temperature (TTRXM =1071.3 deg F) and IGV (csgv=86.087 deg angle) full opening, thus GTG-1 reached **base load conditions** and it's **temperature control mode became active**. This led to decrease in FSR to reduce the Turbine exhaust temperature and save Turbine from over temperature trip, but this on the other hand decreased the Turbine speed (TNH) continuously.

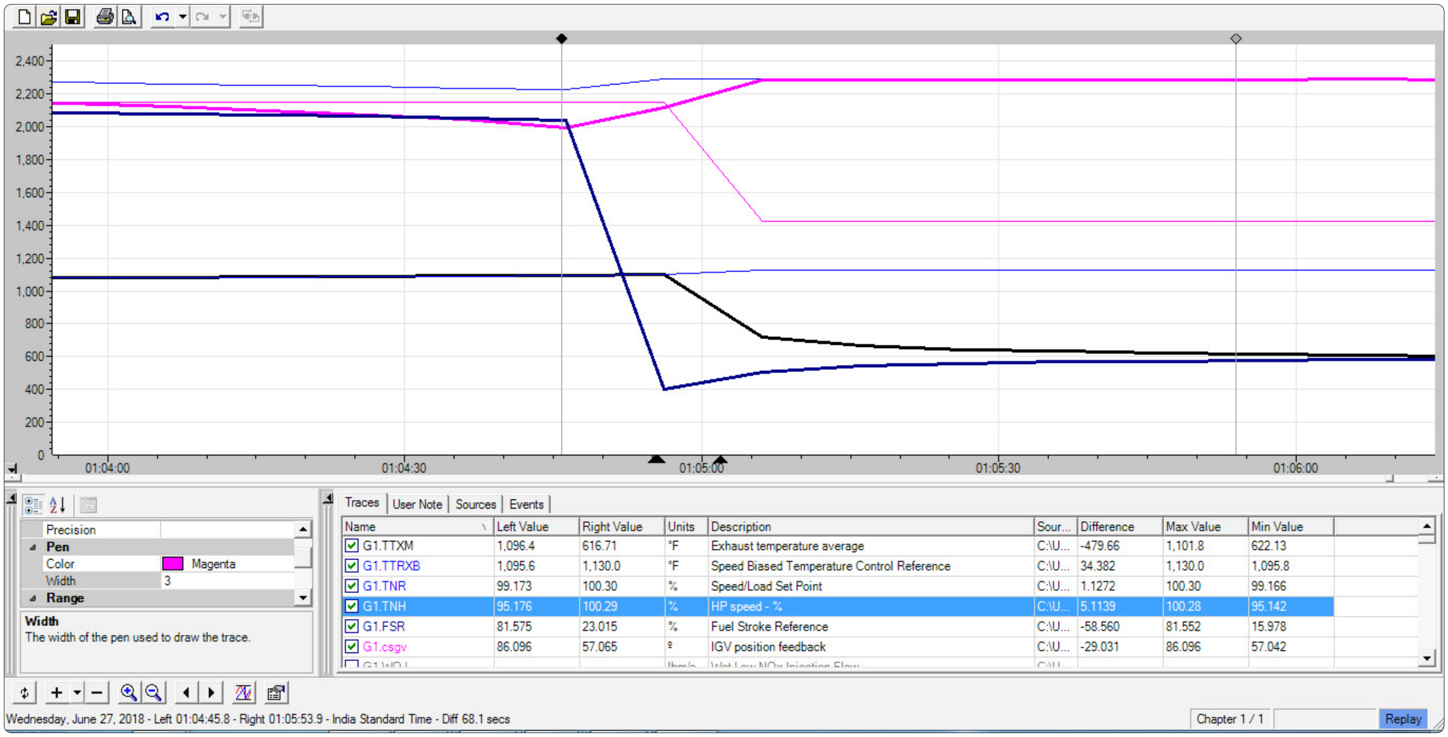


Figure 3: GTG-1 trends before and after tripping.

At 01:04:45.8 hours, due to continuous decrease in the Fuel FSR in order to bring down the Exhaust temperature, the GTG-1 speed went on decreasing and reached 95.142%. Then at a speed of about 94.092 RPM (47.04 Hertz frequency), GTG-1 Generator breaker got opened on "Under Frequency" and the Turbine got unloaded to save the Turbine. This ultimately resulted in the total power failure and blackout conditions in the entire Refinery Units and Township complex.

Analysis of GTG-2 Tripping:

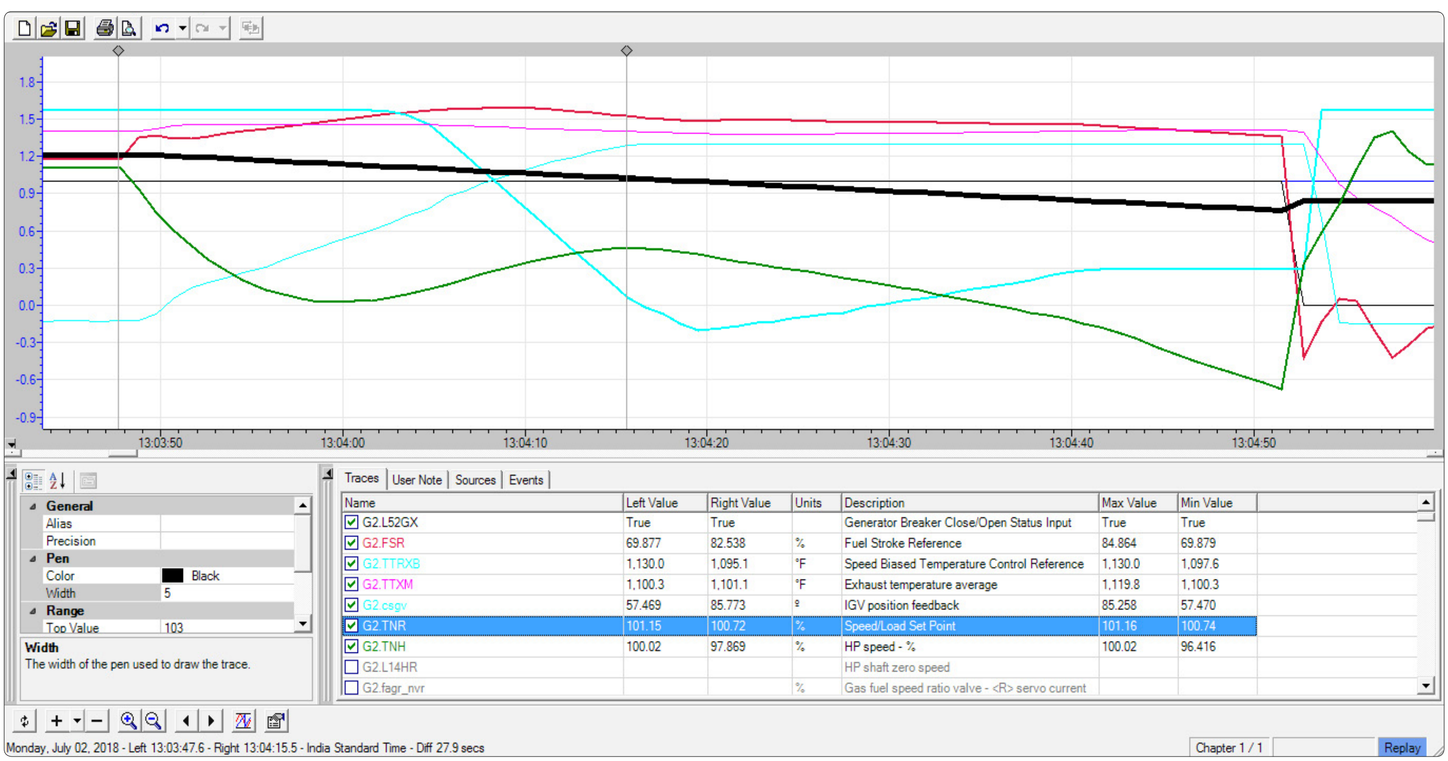


Figure 4: GTG-2 trends before and after tripping.

On 02.07.2018, STG and GTG-02 were running with 6.22 MW and 24.61 MW respectively.

At around 13:03:33 hours STG tripped on actuation of "STG MP Steam extraction trip". After STG trip, the Intelligent Load Shedding Scheme (ILSS) too got actuated leading to a load shedding of around 1.33 MW. Remaining entire load got shifted to GTG-2 which led to increase of GTG-2 load up to 29.50 MW. Due to this, there is sudden increase in the fuel FSR to accommodate the sudden increase in the load.

At 13:04:15.5 hours, GTG-2 went to **base load conditions** and it's **temperature control mode became active** as it's TTXM=TTRXB (= 1100 deg F) and the IGV became full open (85.773 deg C) reached This led to decrease in FSR to reduce the Turbine exhaust temperature profile and save Turbine from over temperature trip, but this on the other hand decreased the Turbine speed (TNH) continuously.

At 13:04:51.3 hours, GTG-2 speed went on decreasing and reached 94.118%. At this point, GTG-2 Generator breaker got opened on "Under Frequency" and the Turbine got unloaded to save the Turbine. This ultimately resulted in the total power failure and another back-to-back total blackout conditions in the entire Refinery Units and Township complex in a very short period of just one week's time.

Why the machines GTG-1 & -2 tripped …. ???

In both the cases, both GTG-1 & -2 went to base load and temperature control active mode before reaching it's maximum expected load of 34 MW after uprating and also before the load shedding/capping limit of 31.5 MW. Simultaneously additional power load of some of the motors of the Refinery and start-up GTG auxiliaries motors further loaded the GTG up-to it's base load condition. This further reduced the speed and thus it's frequency dipped further before the GTG could re-build up and recover it's speed and hence frequency leading to Generator breaker opening on "Under Frequency" and subsequent unloading of the machine and blackout conditions.

Had the GTG load went to base load condition beyond the ILSS set load capping limit of 31.5 MW, then all the extra loads coming on GTG after reaching of base load conditions, would have been shedded and GTG speed could have recovered and hence so the frequency could have again builded up, thus avoiding the tripping. Had there been some mechanism of load shedding on dipping of GTG speed and frequency till restoration of frequency to a safe limit, then GTG would have definitely survived.

Possible reasons why the machine did not load up-to the expected post-uprate load capacity:

Shock load taking capability: Lower loading rate percentage than the rate of shock load coming/thrown-off on the machine due to tripping of the other running machine. Presently the loading rate percentage of both the GTGs GTG-1 & -2 is 8 MW/min. This rate was not sufficient to counter the extra sudden shock load coming into the machine at the present physical conditions of the Turbine and it's auxiliaries.

Machine maximum load taking capacity: The maximum load that a machine could take at a time was not tested nor practically observed till date in both the GTGs. Due to sudden load coming into the running GTG and further extra load coming from the start-up of the motors on the surviving solo running GTG which is already in base load condition, proved to be beyond the maximum limit of the machine's ability which it could take at one single go.

Compressor degradation: Compressor degradation is one of the major causes of output and efficiency loss in a gas turbine. Degradation reduces the air mass flow and pressure ratio, thus reducing power output. Fouling is a major contributor to degradation. This could be one of the contributing factors due to which GTG-1 & -2 could not go up-to as expected 34 MW even after the uprating of both the machines. Due to this, both the machines reached the base load conditions before it's maximum expected load of 34 MW and also before the load shedding/capping limit of 31.5 MW. Due to which the further extra load due to start-up of the motors was not shedded and instead further overloaded the machine already in base load condition and FSR in Temperature control mode. But on the other hand, FSR constantly reduced (as FSR is in Temperature control mode) to decrease and bring the Turbine exhaust temperature under control. Thus on one hand extra load was coming on GTG and on the other hand fuel FSR was on decreasing trend. This ultimately reduced the Turbine speed and in the process Generator breaker opened and Turbine was unloaded on 'Under Frequency" leading to blackout conditions in the entire Refinery Units and Township complex.

Immediate actions taken to prevent the reoccurrence of such incidents:-

Freshly carried out Offline Compressor washing of both the machines GTG-01 & -02. Then Base Load Tests were done for both the machines in presence of the vendor (BGGTS) and found to be approx. 32 MW in both the machines. Improvement in the parameters and performance of the machine was observed in post off-line washing case, e.g., **Comparison before and after compressor washing of GTG#2 is tabulated below:**

Comparison before and after compressor washing of GTG-02							
	Load	Inlet temp	IGV	Compressor discharge pressure	Compressor discharge temperature	Exhaust temperature	FSR
Before	20.2	30	57.01	7.52	331.92	534.57	60.66
After	20.2	30	56.98	7.66	327.63	518.52	60.06
Before	19.9	30	57.00	7.52	331.60	531.95	60.36
After	19.9	30	57.00	7.61	330.36	515.34	58.78
Before	22.2	30	57.01	7.68	336.05	562.59	64.52
After	22.2	30	56.99	7.78	331.46	541.66	63.70
Before	23.0	30	57.01	7.77	336.05	571.14	66.65
After	23.0	30	57.01	7.82	333.64	554.40	65.61
Before	22.0	31	57.01	7.68	336.06	559.26	64.41
After	22.0	31	57.00	7.72	332.96	542.68	63.50
Before	24.3	31	57.01	7.81	338.88	588.33	68.99
After	24.3	31	57.00	7.89	335.50	572.64	67.92

While comparing pre compressor cleaning and post compressor on same load and same ambient temperatures, minor increase in compressor discharge pressure and lower turbine exhaust temperature is observed. Fuel flow is marginally on lower sides in post washing cases. Lower turbine exhaust temperature at same load and same ambient temperatures implies **higher air mass flow**.

Temporarily reduced the ILSS Load capping limit after the review of the various Electrical loads on priority basis of both the GTGs to 25 MW and increased that of STG to 10 MW, so that minimum shock load is thrown on the surviving GTG.

Taking into account the present Refinery load of 34 to 35MW, thorough review of the ILSS load shedding schemes and different Refinery motor loads was carried out considering of various possible situations of GTG and STG trippings. Finally, in ILSS, GTG new load capping is set at 25 MW from original 31.5 MW and that of STG is now 10 MW instead of original 8 MW. Now total load capping is 25+10 = 35 MW. Now when STG trips, GTG load would come to 25 MW, thus no chance of going to base load and overloaded in that conditions. And if GTG trips, then block load shedding will actuate and around 5.5 MW will be hold in STG. Further, in case frequency falls, load will be shed to around 2.0 MW to maintain 48.5 Hz for sustenance of STG. Thus in both the cases either GTG or STG would survive in any one trips and avoid total blackout scenario.

The key parameters of the running GTG are monitored in every shift for thorough analysis and checking of any deviations of the key parameters. Also they are sent to the experts (Vendor BGGTS) twice in a month for further review of any deviations at their ends.

Intermediate solutions

Increase the loading rate percentage from 8 MW/min to 16 MW/min ---- This is under study before final implementation. The main objective is to increase the per minute loading rate of the machine so that it could suddenly take the high extra shock load if any sudden high loads come into it on tripping of the other running units so that it survives and avoids blackout conditions.

Long term actions

Electrical stability study for changing the load shedding scheme from MW based to Frequency based and also to tune the Gas turbine for max shock load: Presently the Intelligent Load Shedding Scheme (ILSS) is based on the total load (MW based) of the Refinery. The Refinery loads would be shed on priority basis on actuation of the ILSS system to save the machine from tripping on overloaded. But in the last two trips, this system proved to be not helpful up-to some extent. If the loads would have been shed in both the trips cases, then the machine could have survived from unloading on "Under Frequency". But it did not happened as the base load came before the set limit of ILSS actuation. As a result the running GTG kept on taking the extra load thrown on it and as a result it's speed and hence frequency constantly went on decreasing till unloading on "Under Frequency". To counter this problem, we are on the path of changing the load shedding scheme from MW based to Frequency based so that once the frequency starts to dip the machine, the ILSS would take care of the machine's load conditions and keep shedding as per the reduction in rate of frequency. Also the machine would be tuned to such that the machine could take sudden extra load thrown on it or sudden extra load shed from it keeping the safe limit of the frequency of the grid.

Study on the machine to increase the loading capability during the shock load scenario (Short time peak load capability): The study would be carried out in details taking into considerations of the physical status of the machines and it's auxiliaries' healthiness to increase the loading capability during the shock load scenario. Study would be made to loading rate percentage from 8 MW/min to 16 MW/min so that the machine could sustain and take sudden huge extra load coming on it without being overloaded. The peak load of the machine would be taken into account and calculated based on the current parameters of the machine running at that moment.

Planning for implementation of the following under the guidance of the vendor BGGTS:

Implementation of Online water washing system of Compressor in GTG: The machine which once was tested satisfactorily up-to 31 or 32 MW and projected to load up-to 34 MW after it's up-rating could not load up-to that load after a year or so. Thus we saw that even after periodic off-line compressor washing of the machine, it's base load decreased and could not load up-to 34 MW as expected after a year or so. Hence, in addition to the existing Off-line water wash system of the compressor, the provision of On-line water washing system is under study in details in order to keep the compressor blades clean, tidy and free from fouling as far as possible. This would help us to bring into confidence of the performance and reliability of the compressor and help the Turbine to reach it's optimum load as tested without any fail during the time of need and emergencies.

Implementation of OSM (Online System Monitoring) **software:** Through this system, the data of the running GTG would be shared directly with the experts of Vendor and OEM BGGTS for continuous online thorough and minutely monitoring of the parameters of the GTG. This would help us to take corrective actions in early stages before going into further degradation and deterioration.

Implementation of Peak Load acceleration Block: A new provision in the software would be developed which would online calculate the projected peak load (or maximum projected load) taking into account of the parameters of the running GTG at that time. This would help us to check how far or near we are running the GTG from the projected peak load. This would alert us and help us to keep the running GTG at some safe allowable limit from reaching the base load or peak load conditions. We could decide on how far we could further load on the running machine and how much extra sudden load would be thrown off on the running survival machine on tripping of the other running machines in the same grid. This would help us to take necessary corrective actions on time and avoid tripping on sudden overload scenario.

Conclusion

Both the tripping cases of GTG-1 & -2 were a great and new learning experience for all of us. We could discover new problems and shortcomings of GTG and discover new solutions to counter them on intermediate, short time and long term basis. Apart from Off-line compressor wash, the implementation of On-line water washing system of the compressor would help us to constantly maintain the performance of the compressor and hence the turbine performance up-to the optimum output level on a prolonged sustained basis. This would definitely increases the chances of survival of the machine on getting sudden high shock load. For a CGP/CPP with no grid connectivity facility, periodically base load conditions testing and the maximum shock load absorbing capacity testing of the machine needs to be carried. These testing may be included in the GTG best operating practices by all. This would bring into confidence and reliability of the machine during the time of emergency and tripping of any running machines to avoid total blackout scenario. Thus both the tripping cases of GTG-01 & -02 were a blessing in disguise as it gave us an ample opportunities to discover a lot of new angles of seeing the GTG's performance and its sustenance and improvement scopes.

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