Black Start Experience for Gas Based Power Plant in Indian Grid

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***Abstract*—Crisis Management Plans are important for enhancing the resilience of the bulk electric power supply system. Fast restoration from a partial/total blackout can reduce the economic loss and customer discomfort from power supply interruptions. Black start mock drills are essential for testing the equipment capabilities in restorative mode. They are also an opportunity for operators in Generating Station, Substation, and Grid Control Room to gain first-hand experience of System Restoration. In India, several hydro and Gas units are equipped with black start capabilities. This paper shares the experience of the maiden black start mock drill conducted at a Gas based power station connected at 220 kV level Western Regional Grid in India. It involved black start of a unit, charging of a dead bus, charging a 220 kV line, building up a subsystem with load, operating in islanded mode and finally synchronizing with the grid. Lessons learnt from the success of this exercise paved way for testing of black start capabilities at other Gas Power Stations in Western Region.**

Keywords—Black Start, Indian Grid, Island, Gas Power Station, Western Regional Load Despatch Centre.

I. INTRODUCTION

The Indian power system is one of the largest synchronized power system in the world after the synchronization of its Southern Regional (SR) grid with rest of the grid on 31st December 2013. The total installed capacity is more than 250 GW [1]. The reliability of the grid has increased with the synchronization of SR Grid and so has the need for better preparedness for fast system restoration in case of a blackout.

Two successive blackouts were experienced in India in July 2012. Although the system was restored within few hours on both the occasions, yet it was observed that the restoration could have been faster if more number of units could have contributed in black start. The Enquiry Committee that investigated the Grid Disturbance/System Restoration in July 2012 observed that the delay in extension of start-up supply to several thermal units could have been avoided if certain subsystem created by black start units could have been prevented from collapse by better coordination among generating station, substation and grid operators [2]. For example, Teesta units black started but the island collapsed several times on various reasons. The above experience revived the focus on black start drills to enhance preparedness and improve coordination during crisis. The Central Electricity Regulatory Commission (CERC) had also directed to conduct the mock drill on all the black start units on regular interval and monitor the healthiness of black start stations [3].

The Indian grid is demarcated into five regional grids, which are synchronously connected with each other. Western regional grid of India is the grid with highest installed capacity and second highest demand [1]. Large pit-head thermal stations are located in Chattisgarh and North-east Maharashtra while major load centres as well as Atomic Power Stations are located in Southern Gujarat / Western Maharashtra. Considering the availability of several Gas power stations in Southern Gujarat near load centre, a mock drill for system restoration of Southern Gujarat with the help of black start of one unit of Kawas Gas Power Station (located in Surat) was contemplated. The unit had successfully black started and contributed in System Restoration post Grid Disturbance of

09th December 1995 and 30 July 2002 in Western region. As per the Western Region System Recovery Procedure, the Kawas Gas Power Station is assigned the following responsibilities during restoration:

1. To extend survival power and start up power to Kakrapara and Tarapur Nuclear units
2. To achieve restoration of priority load in Surat city
3. To extend start up power to thermal stations in Southern Gujarat

As a part of routine, the black start generator at the station is regularly tested. However, after 2002, there had been no other actual experience of testing its capability.

Section II introduces the details of the black start station while section III discusses the planned activity during the mock drill. Section IV focusses on the mock drill activity, which was carried out, and section V presents the various analysis based on the real time data for the mock drill. In the end, section VI focusses on the lessons, which are learnt during the activity.

II. Kawas Gas Power Station (NTPC)

The Kawas Gas Power Station is a gas-fired power plant of National Thermal Power Corporation (NTPC Ltd.) operational since 1992-93. It is located at Aditya Nagar in Surat district of Gujarat. It is a combined cycle gas turbine (CCGT) power plant with total installed capacity of 656.2 MW. It has four gas turbines with total capacity of 4 X 106 MW and two steam turbines with capacity of 2 X 116.1 MW. The Diesel generator of 2850 kW is available for black start. Figure 1 shows the geographical location and its electrical connectivity. Unit transformer is of 11.5/220 kV capacity.

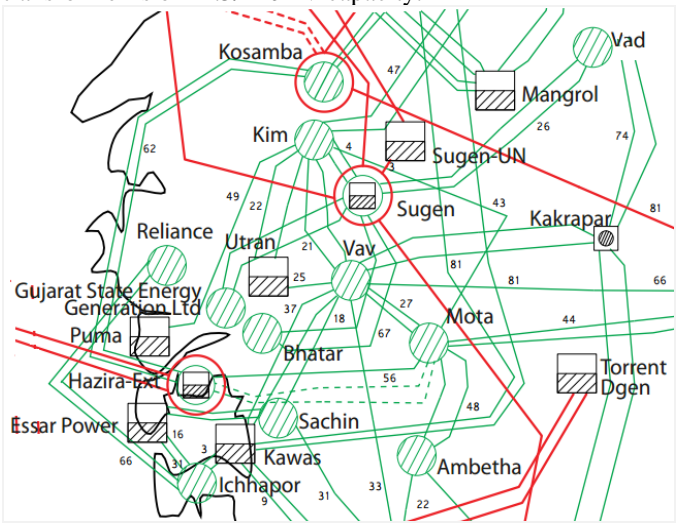

Fig. 1. Geographical map of Kawas Power Plant and its eletrical connectivity. Red lines are 400 kV and Green lines are 220 kV Transmisiion lines.

Being a gas based power plant equipped with a 2850 kW Diesel Generator set with auto start facility, it can be started quickly and can be synchronized with the grid in few minutes. Being at the boundary of Maharashtra and Gujarat, gives an additional advantage to provide startup power to nearby station in Maharashtra and Gujarat whichever is ready first. In view of this, its readiness for black start is very important and conduction of mock drill is essential at regular intervals. The next section describes the objective and preparedness for the mock drill carried out for the Kawas power plant.

III. Mockdrill Preparation

Any black start mock drill activity consists of the following 5 steps as tabulated under in Table 1.

TABLE I. Black start Mock Drill Activity

S.N.	Activity	Remarks
1	Preparation	Preparation of Procedure and circulation, Public notice, Bus segregation and Subsystem identification.
2	Controlled Separation & Black Out	Controlled separation of the subsystem (Black Start source + line + load) from grid, Blackout of the sub-system
3	Self-start of generator & build-up of the subsystem	Black Start and dead bus charging + line charging, Load build up in islanded system, Frequency variation
4	Synchronization with rest of the grid	Synchronization with the grid at an intermediate grid substation
5	Information dissemination & Gap identification	Compilation of report, dissemination of information, Identification of areas needing improvement

A detailed plan for mock black start drill was prepared after several rounds of deliberations between engineers of WRLDC, SLDC Gujarat, Kawas Power Station and DGVCL (Distribution Utility of Gujarat). Kawas Unit No. 2A was selected for mock drill activity. Since at least 35 to 40 MW load was required for stable operation of the unit in islanded mode, the loads at 66 kV Pal, Pala and Kosad feeders of 220/66 kV Ichhapur sub-station were identified for the exercise. Public notice was issued to alert the customers of the identified area regarding interruption of power supply during the mock drill. In order to test the coordination between Operators of Generating Station, Substation and Grid Control room, it was decided to synchronize the island at a location other than the power station. Since synchronizing trolley was not available at 220 kV Ichhapur (also known as Ichhapore), synchronizing point was chosen as 220 kV Vav or 220 kV Essar. The drill was initially planned to be conducted in September 2013 but had to be abandoned due heavy rains and flooding of Surat city. The drill was later conducted on 15th Oct 2013.

IV. Black start Mock drill at Kawas

The black start mock drill on Kawas Power Plant was finally conducted on 15th October 2013. The mock drill activity was initiated at 09:00 Hrs after confirming the field scenario and bus arrangement at Kawas and Ichhapur S/s. The 220 kV Bus Bar arrangement at Kawas (NTPC) was done in a manner to have the black start unit 2A, Station Transformer-1, 220 kV Kawas-Ichhapur circuit 2 and 220 kV Kawas-Vav circuit 1 on 220 kv Bus 2 and rest of the feeders on 220 kV Bus 1.

The 220 kV Bus Bar arrangement at Ichhapur station was also similar where the 220/66 kV 100 MVA ICT 3, 220 kV Kawas - Ichhapur circuit 2 and 220 kV Essar-Ichhapur circuit 2 were kept on Bus 2 while rest of the feeders on Bus 1. At 66 kV Bus of Ichhapur where the load feeder were there, the 220/66 kV ICT 3 and 66 kV Pal, Pala and Kosad feeders were kept on Bus 2 and remaining feeders on Bus 1. The overall arrangement for black start mock drill is shown in the figure 2.

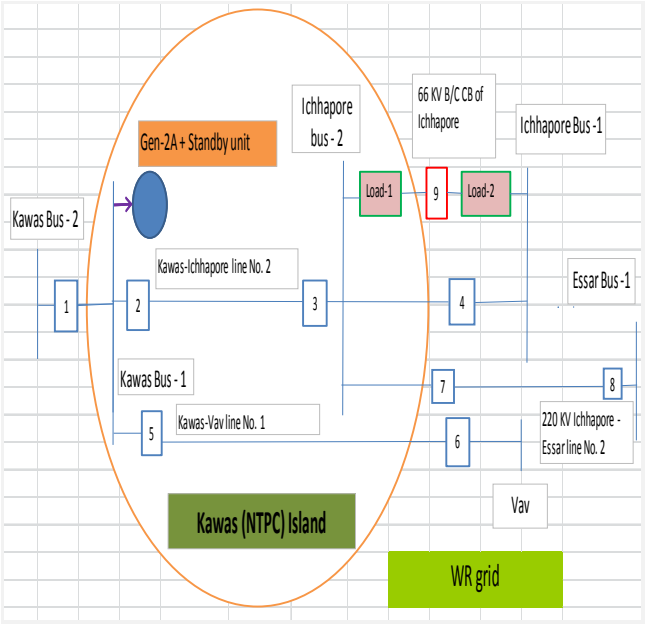

Fig. 2. Schematic Diagram of the island formation for mockdrill activity. Numbers indicate the breaker which were opened as per their number.

In the mock drill, there were two stage i.e. first to create the island and analyse its characteristic and second was to blackout the island and black start it for synchronization with the grid. The steps taken for black start mock drill first stage are as following:

1. At 09.30 Hrs, Kawas generating plant was informed to start Unit 2A.
2. At 09:47 Hrs, Kawas Unit 2A was started and generation was increased to 40 MW.
3. At 09:47 Hrs, 66 KV Bus coupler at Ichhapur S/S was opened. The load on 66 kV auxiliary bus was around 40 MW.
4. At 10:19 Hrs, 220 kV bus coupler breaker at Kawas end was opened.
5. At 10:22 Hrs, 220 kV bus coupler breaker and 220 kV Ichhapur – Essar line circuit 2 at Ichhapur sub-station end was opened.
6. At 10:30 Hrs, load-generation balance was confirmed by almost zero power flow on 220 kV Kawas - Vav circuit. 1.
7. At 10:37 Hrs, the island was formed by opening of circuit breaker of 220 kV Kawas -Vav circuit 1 from Kawas end.
8. After observing the island's stability, load was varied by opening 11 kV feeders to analyze the frequency response of the island.
9. Then to blackout the island, the Kawas Unit 2A generation was in synergy with load of island and unit was tripped at 11:21 Hrs.
10. The island operated for around 44 minutes.

With this, the first stage of black start mock drill was completed and now second stage was started i.e. black start the unit and then recreating the island and at the end its synchronization with the grid. The steps involved during this stage are as following:

1. At 11:23 hrs, black start DG set was started manually and at 11:35 hrs, Kawas Unit 2A was started through DG set.
2. At 11:45 hrs, 220 kV dead Bus 1 was charged by closing circuit breaker of generator transformer of Unit 2A.
3. At 11:52 hrs, 220 kV Kawas-Icchapore circuit 2 was charged and gradually load was increased at 220 kV Ichhapur Bus 2. Nominal variation in frequency and voltage was observed in view of load-generation change.
4. The black started island was then operated for around 71 minutes. Load to the tune of 40-45 MW load was being catered by the sub-system during this period.
5. At 12:44, 220 kV Kawas-Vav circuit 1 was charged from Kawas end on 220 kV Bus 2 and to synchronize the island with the grid, the circuit breaker at Vav end.
6. Again at 13:23hrs, island was isolated by opening 220 kV Kawas-Vav circuit 1 line in synergy with load-generation balance.
7. At 13:29 hrs, the 220 kV Essar Ichhapur circuit 2 was taken in service from Ichhapur end on Bus 2 and the island was synchronized at Essar end by closing breaker at 13:43 Hrs.
8. After this at 13:52 hrs, 220 kV Essar-Vav circuit 1 was taken into service followed by closing 220 kV and 66 kV bus couplers at Kawas and Ichhapur end.
9. At 14:00 hrs, black start mock drill was declared successful.

With this, the black start mockdrill activity was completed at Kawas station and the objective with which it was planned was also achieved. Still, the analysis of island response is very essential to analyze in detail for getting into the stability issues. The next section discusses the various data collected for the black start mockdrill activity and its quantification and analysis.

V. Analysis of Black Start Mockdrill at Kawas

In order to examine the performance of black start mock drill, three parameters can be defined which are the duration of island and its synchronization, frequency variation and voltage

variation. The time taken for achieving the key milestones during restoration drill is shown in table 2.

TABLE II. TIME LINE FOR MOCKDRILL ACTIVITY

Activity	Time (Minutes)
Time taken to start DG set after black out of Island	2
Time taken to charge dead bus at Kawas	10
Time taken to charge dead bus at Ichhapur	7
Time taken to connect first load post black out scenario	32
Duration of stable island operation after successful black start and building up the of the island till synchronization with grid	71
Time taken to synchronize the island with Grid	44

It took around 32 minutes to start the unit and extend supply to the identified load at Icchapur. Figure 3 illustrates the frequency of Island and the grid during various step of mockdrill. During actual black start and island operation, i.e. Island operation II as indicated in figure 3, the frequency of island varied between 49.2-52.0 Hz. After addition of load the subsystem frequency was maintained between 49.2-50.71 Hz i.e. 1.51 Hz variation.

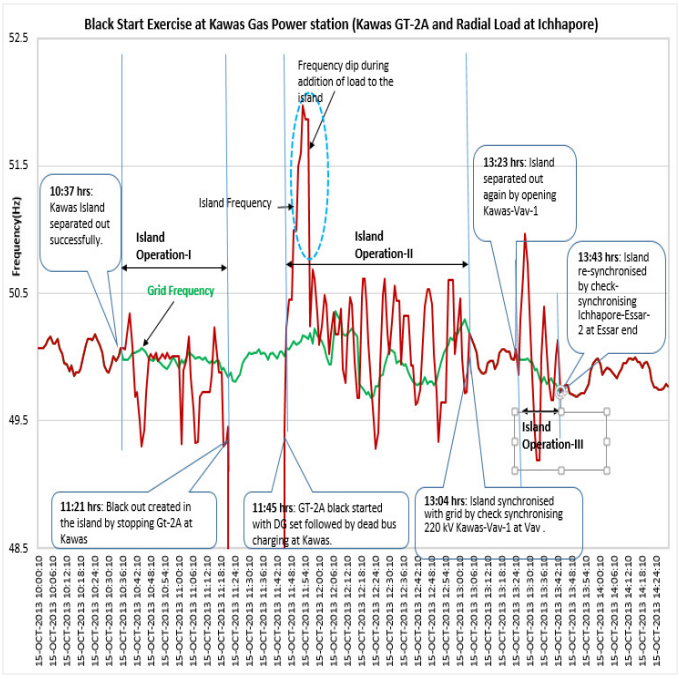

Fig. 3. Grid and island frequency during various stages of the mockdrill activity for Kawas.

Figure 4 shows the frequency of grid and island and the voltage of 220 kV Generator Bus. It can be observed that voltage variation was within 215-222 kV which is found to be good. The voltage was high initially while starting of the unit which gradually reduced with MVAr absorption by generator and connection of the load. The overall voltage was contained within the operating limit i.e. 220 ± 10 % kV.

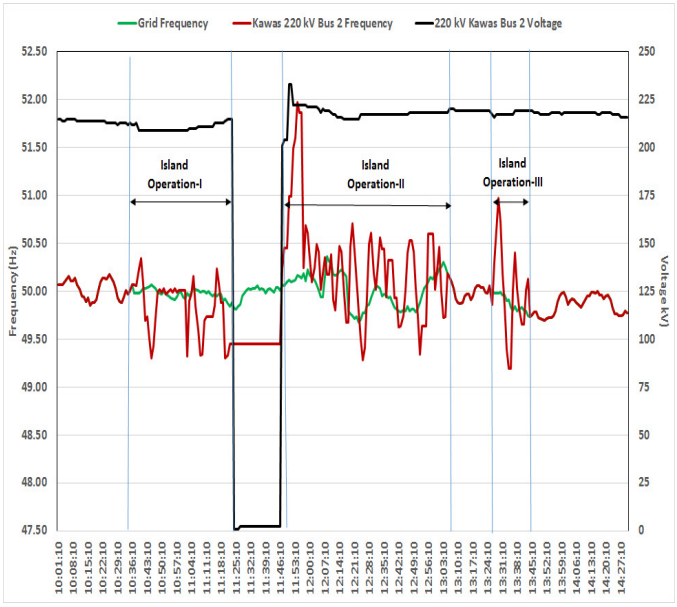

Fig. 4. Bus voltage of Generator Bus of the Island and the Frequency of Grid and Island during the various stages of operation.

Thus, it can be noted that the performance of the Kawas Gas unit was satisfactory during black start, islanded operation and synchronization.

VI. LESSONS LEARNT DURING THE MOCK DRILL

Any blackstart mockdrill gives a lot of experience to the power system operator of generating stations, sub-stations and control centres. Few papers on the past experience of black start exercise may be referred from [4-7]. These exercises have helped in preparing system restoration procedure for the Western Regional grid [8]. The key learning from black start exercise of Kawas Gas Power Station are as followings :

1. Gas Power Units can black start, charge a dead bus, charge EHV transmission line and build a subsystem with load. The subsystem could them extend start up supply to other stations in the vicinity.
2. Kawas Gas Power Unit can provide primary response to maintain frequency within acceptable range in a sub-system. It can also absorb/inject reactive power to regulate voltage and maintain it in within acceptable range.
3. Unlike normal operation, the frequency and voltage during system restoration may vary significantly. Therefore setting of underfrequency and overfrequency relays may have to be reviewed during system restoration.
4. The circuit breaker sequence should be known to the operator coordinating the black start. These may be documented in the Standard Operating Procedure available at the substation.
5. Synchronising trolley needs to to be provided at all substations in the identified restoration path to facilitate synchronization with other islands.

6. Knowledge of the load characteristics is important to maintain stability in the subsystem.
7. Healthy telemetry and speech communication between the control centre and substation is vital for coordinating systyem restoration.

This mock drill was first of its kind as it was the first successful black start mock drill on a gas based interstate generating station (ISGS) in the Western grid. Based on the learnings from this exercise a similar exercise was successfully conducted at Gandhar Gas Power Station in Bharuch (Gujarat) on 7th December 2014.

SUMMARY

The Black start mock drill helps in assessing the preparedness for system restoration and crisis management. They help improving the coordination between the utilities who would have to collaborate during actual restoration. These exercise help in identifying the deficiencies that are required to be addressed in order to have fast restoration.

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