Module 6 : Preventive, Emergency and Restorative Control

Lecture 31 : Power System Restoration

Objectives

In this lecture you will learn the following

- Restoration of a power system after a blackout has taken place.
- Problems associated with restoration.
- An Illustrative Example

After a blackout

If a blackout (a near total loss of generation and load) takes place, efforts have to be taken to bring back the system to a normal state at the earliest. It may surprise you to know that this (black starting!) is not an easy task. We shall see why in this lecture.

Once a generator is tripped, restarting it requires a significant amount of power. Power is required for 2 types of activities:

a) Survival Power: For emergency lighting, battery chargers etc. Usually the requirement is 0.3% of the generator capacity.

b) Startup Power: For starting power plant auxiliaries (pumps etc.) Interestingly, nuclear and thermal units require approximately 8 % of the unit capacity for auxiliaries alone! Therefore, a 500 MW generator requires approximately 40 MW for running its auxiliaries.

Hydro and Gas units, on the other hand, require only about 0.5-2% of unit capacity for auxiliaries and can be started usually from in-house DG sets.

The major steps required for restoration are:

a) Islands which have survived need to be stabilised for frequency and need to be used for starting other units

b) Hydro/Gas units which require less startup power need to be started using in-house DG sets.

c) Larger thermal units need to be fed "startup power" from: 1) Islands which have survived 2) Blackstarted generators 3) Other synchronous grids (temporarily)

d) Started units are synchronised with one another.

e) Loads and Generation have to be matched as much as possible to avoid large frequency variations. Governors have a major role in stabilizing frequency in an island.

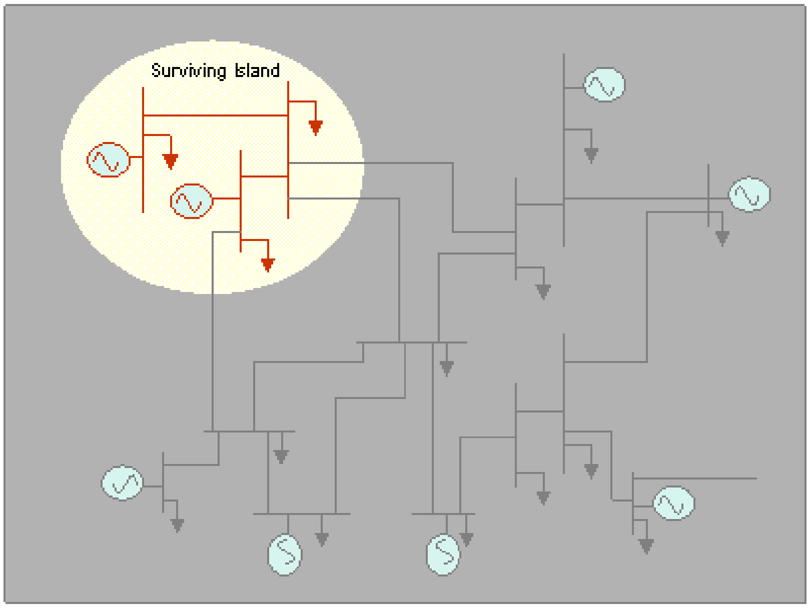
Problems in Restoration

a) Securing Islands

After a blackout a few islands may survive due to separation of the system in time. A few hydro or gas generators could be blackstarted using in-house D-G sets. Therefore some small pockets will be there in the otherwise blacked out grid wherein generators are supplying some loads. However, the situation in these islands is usually precarious due to the small number of generators within the island (having very little cumulative inertia).

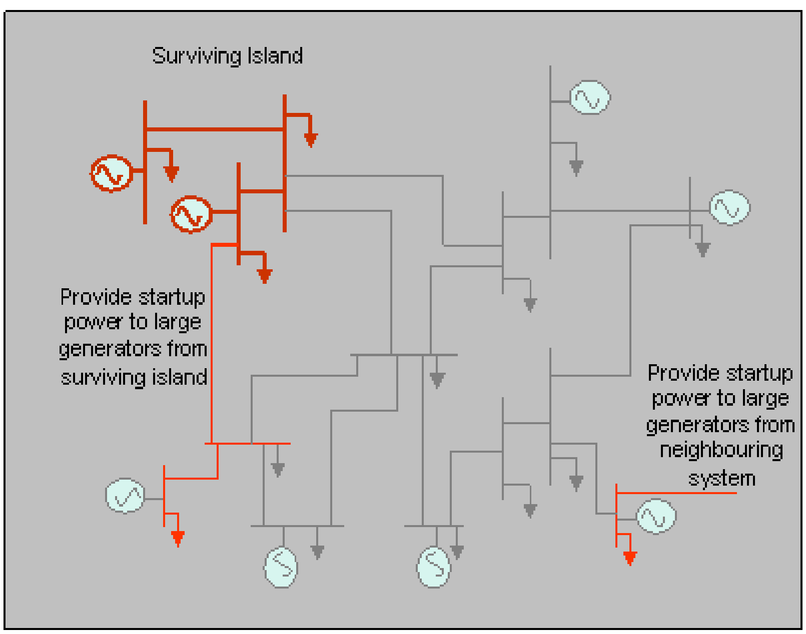
Recall that the initial rate of change of frequency is determined by *cumulative machine inertia* and the initial load-generation imbalance, while the final settling frequency is determined by the governor and load frequency characteristics (see Module 3).

Therefore if the load in the island is fluctuating (for instance, traction loads), the rate of change of frequency within the island due to fluctuating loads may be quite large -- large enough for the island to collapse due to excessive frequency variations - causing generators to trip. Therefore control of generated power (by governors) and frequency based tripping or energisation of load is important.



Black-starting of large generators is done by availing startup power from other started generators or islands. Startup power may also be availed from neighbouring synchronous grids if an AC transmission link exists (normally disabled). Unfortunately, startup power cannot be availed via DC links (which use AC line voltages for commutating thyristors), because AC voltages are not available in the system which is blacked out.

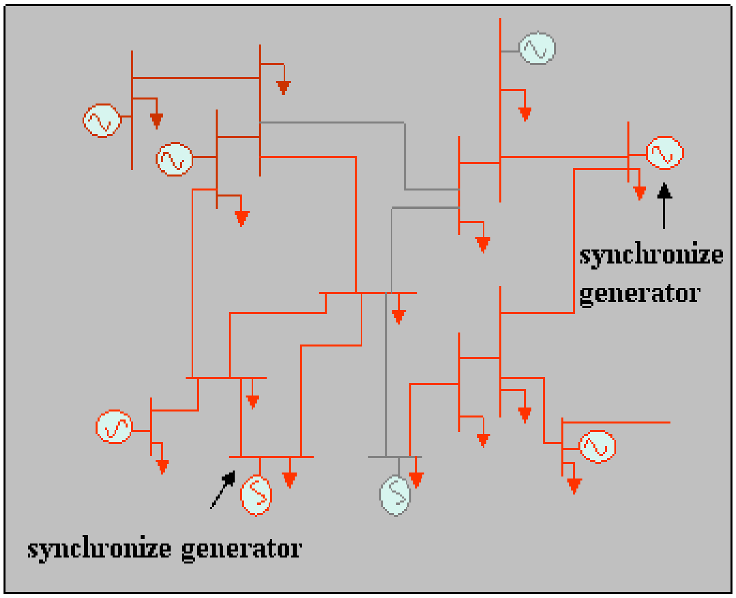
Therefore a generator at Vindyachal (near the border of the western region and northern region grid of India, which are not synchronised but exchange power through DC asynchronous links during normal conditions) can avail startup power through *an AC line* from the northern grid.



Problems in Restoration

b) Extending Power to Loads from Generators which are black-started

The next step in power system restoration is to supply loads from black-started generators. Some of these loads may be in the form of the startup (auxiliary) loads of other larger generating plants which need to be black-started.



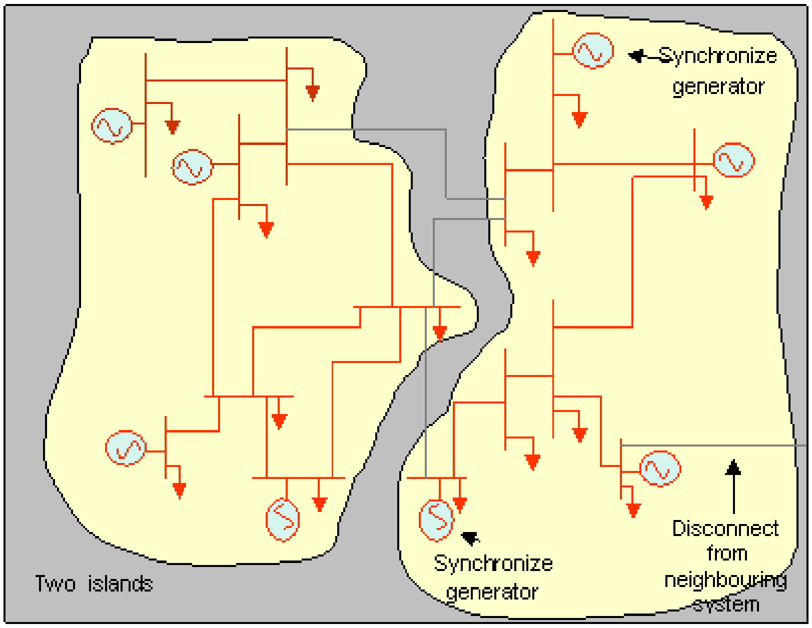
These loads are supplied via transmission lines. Enregising a transmission line initially without any load can cause **over-voltages** (why ?). This is avoided by:

1. Energising fewer high voltage lines
2. Operating generators at minimum voltage levels (by keeping filed excitation low)
3. Deactivating switchable capacitors
4. Connecting shunt reactors and tertiary reactors
5. Adjusting of transformer taps
6. Pick up loads with lagging power factor
7. Charging more transformers
8. Charging shorter lines
9. Operating synchronous condensers / SVCs where available
10. Avoiding charging lines with series capacitors

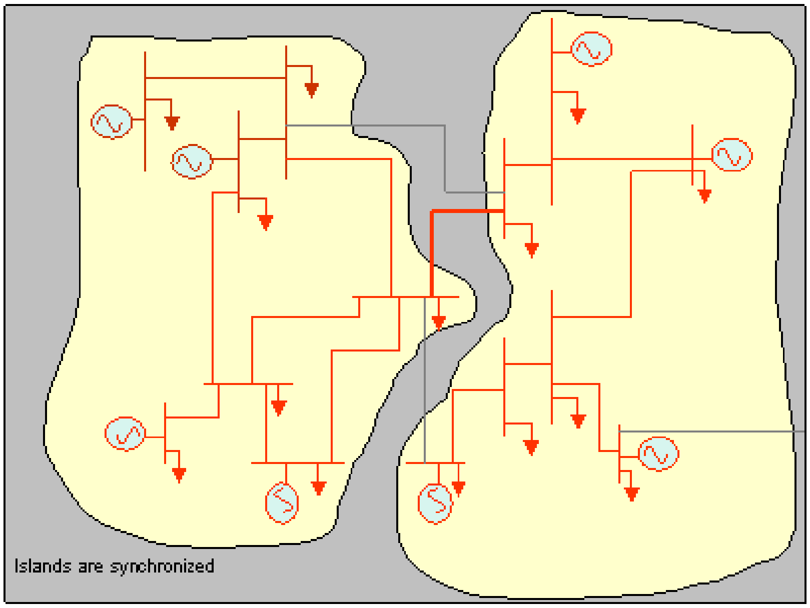
Problems in Restoration

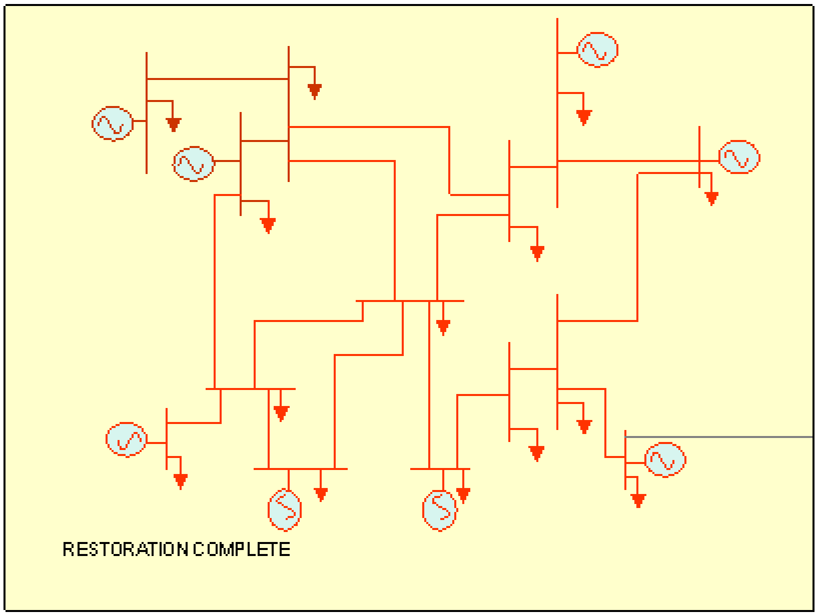
c) Re-integrating the grid

As mentioned before, some islands which have been secured should be connected with each other so that the system cumulative inertia increases, a better generation-load balance can be achieved by encompassing a larger set of loads and generators, and better redundancy in transmission and generation is achieved.



Note that an important step in reconnecting islands to one another is "synchronisation". While each generator has synchronising facilities, the interconnection of two islands may have to be done at some bus in the network wherein such facilities are available. The basic requirements for successful synchronisation of two systems are the same as those for an individual generator connected to a large grid (see Module 2). In particular, the frequencies should be practically the same and phase angular difference at the instant of connection should be small. If two systems are connected at an inappropriate instant, then the generators in both islands will not synchronize, and the situation will be akin to an out-of-step scenario; the link will have to be disconnected.





Restoration : A practical example

The **sequence** of actual restorative actions which were taken after the Northern Grid Collapsed in January 2001 are given below.

Details of the blackout are given in the previous lecture. Again, what we show here is only a "reconstruction" of what probably happened, based on manual observations and recorded measurements. Since all measurements and observations are not necessarily synchronised with a common clock, some amount of correlating or "pieceing together" of evidence is required. However some uncertainty is expected in the final sequence. A rigourous approach would involve simulation (numerically evaluating the response) of the entire sequence on a computer and correlating the same with the observed data. However, this is not shown here.

The system was restored in two parts. The south-eastern part was restored by taking power from Western Region (a neighbouring grid) through an AC line which runs parallel to the HVDC back-to-back station at Vindhyachal.

The western part was restored after starting Bhakra (hydro) machines. Chronology of restoration process of Eastern and Western parts is given below :

Restoration of Eastern Part (2nd January 2001)

At 04:59 one machine of Rihand (Hydro generation) was started.

At 05:10 hrs startup power from Western Region (WR) was extended to Singrauli generators through AC bypass of HVDC back-to-back station at Vindhyachal.

05:38 hrs WR power was further extended to Rihand Generators by charging 400 kV Singrauli – Rihand I.

06:32 hrs WR power was also extended to Kanpur by charging 400 kV Vindhyachal – Kanpur line.

At 07:01 hrs 400 kV Kanpur – Panki I was charged.

At 07.42 hrs. Rihand (H) - Anpara 132 kV line charged and Anpara unit cleared for light up at 08.15 hrs.

The power was extended to Mainpuri at 12.38 hrs.

Between 09:11 and 11:20 hrs following units were synchronized:

Singrauli unit 6 (500 MW) at 09:11hrs

Rihand unit 1 (500 MW) at 09:54 hrs.

Singrauli unit 5 (210 MW) at 10:48hrs

Singrauli unit 3 (210 MW) at 11:20hrs

Since there was considerable delay in getting Bhakra (hydro) power at Dadri, WR Power was extended from Kanpur to Agra at 11:44 hrs by charging 400 kV Kanpur – Agra line and further to Ballabhgarh and Dadri at 11:57 hrs and 12:01 hrs respectively. However, 400 kV Ballabhgarh – Dadri I tripped on over voltage at 12:17 hrs.

Ballabhgarh Interconnecting Transformer (ICT) was charged to extend power to Ballabhgarh at 12:18 hrs. 400 kV Agra – Ballabgarh line tripped at 12:39 hrs

Anpara unit-4 synchronised at 12.50 hrs.

Restoration of Western Part

As specified in Black Start Procedures, immediately after the grid failure Bhakra hydro station attempted two times to revive the system at 05:05 hrs. and 05:40 hrs. but the machines could not be stabilized.

Unit 4 at Bhakra (L) started at 06:00 hrs.

At 07:07 hrs. power was extended to Panipat by charging 220 kV Bhakra – Ganguwal – Dhulkote – Panipat sections.

At 07:28 hrs Panipat – Dadri line was charged. This line however, tripped on over voltage. The line was again charged at 07:33 hrs but tripped immediately on over voltage.

The line was again charged from Panipat end at 08:47 hrs utilizing an open circuited 220/400 kV transformer at Dadri as a reactor to limit over voltage. Dadri – Ballabhgarh I was charged at 09:08 hrs but tripped immediately along with Panipat line on over voltage. At 09:19 hrs Panipat – Dadri line was again charged. Dadri Gas Turbine generators synchronized and started generating 200 MW.

The following 400 kV lines were charged between 09:29 to 09:54 hrs from Dadri end

Dadri – Ballabhgarh 09:29 hrs, Dadri – Murad Nagar 09:39 hrs (tripped at 10:10 hrs), Ballabgarh - Agra 09:48 hrs.

Dadri – Mandola I 09:54 hrs, Agra – Auraiya 10:00 hrs

At 10:16 hrs Bhakra island collapsed due to under frequency.

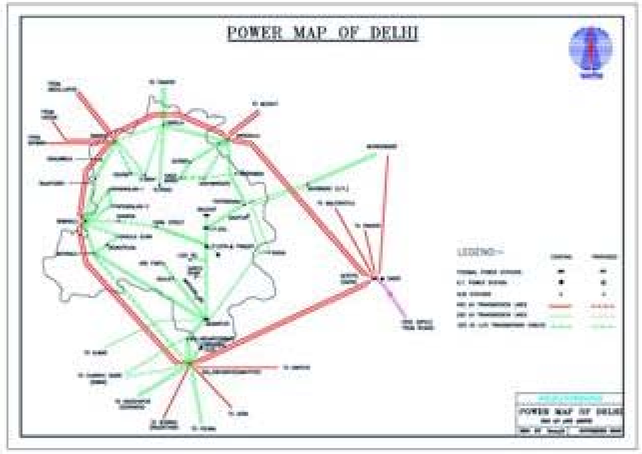
At 10:33 hrs 1st unit at Bhakra(R) station started but tripped at 10:42 due to large fluctuations in loads. It was again started at 10:46 hrs but again tripped at 10:52 due to same reasons as above. The unit was again started at 11:00 with manual regulation of load by locking the load limiter in steps. Power was extended to Panipat at 11:14 hrs. At 12:04 hrs 220/400 kV Inter-Connecting Transformer 2 was charged.

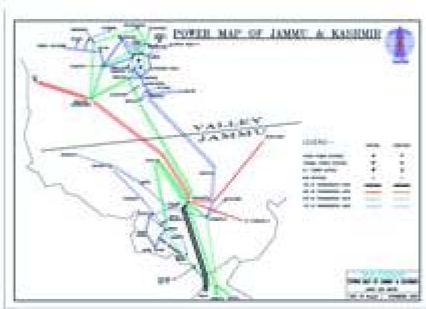
Power to Badarpur was extended from Bhakra system through Panipat - Charkhi Dadri - Ballabhgarh at 13:08 hrs.

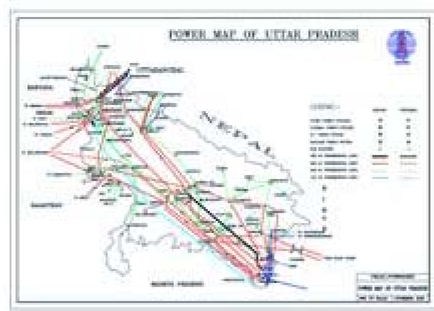
Bhakra power was not extended to Dadri as it received WR power from Ballabhgarh.

The eastern and western parts of the grid were synchronized at 13:32 hrs.

(Click on any map to enlarge: Can you identify the major 400 kV buses mentioned above?)







(the above maps can also be viewed from this site : http://nrldc.org/nrldc/powermaps.asp)

Recap

In this lecture you have learnt the following

- Nature of problems faced when restoring the system after a blackout.

- An example : Restoration of the Northern Grid after the 2001 blackout.

Congratulations, you have finished Lecture 31. Please view the next slide for concluding remarks for this module.

We now summarize what we have learnt in this module :

a) Other than routine scheduling of real and reactive power flows based on economic and power quality criteria (i.e. maintaining a good voltage and frequency), a system operator monitors the health of the system by analysing measured data during real operation

b) The system operator "checks out" the health of the system by mimicking the system behaviour (for different disturbances) on a computer for a given operating scenario (obtained from measurements). This is called security assessment.

c) Based on computer simulations, if the system is percieved to be in an alert state (i.e., a system will not be able to withstand credible contingencies), then operator carries out preventive control actions like generation re-scheduling and load curtailment.

d) Due to inadequate preventive control or lack of anticipation, a system may go into an emergency if contingencies occur.

e) Emergency Control actions like generator or load tripping may prevent total collapse. Failure of emergency control actions may result in a complete blackout.

f) Restoration of a power system after a blackout is not a trivial process and requires prior planning to prevent frequency or voltage problems. During the initial stages of restoration, a system is particularly vulnerable to these problems.