Procedure for Assessment of

Frequency Response Characteristic (FRC)

Of

Control Areas

in

Indian Power System

Power System Operation Corporation Ltd

In association with

Forum of Load Despatchers (FOLD)

INDEX

1. Background

1.1. The objective of this procedure is to develop a common understanding among all the control areas and other entities responsible for the reliable operation of each Interconnection in India for computation of FRC.

1.2. This procedure has been developed to monitor the compliance of Regulation 5.2. (f) of the Indian Electricity Grid Code, 2010.

2. Definitions

2.1. As per IEGC "Control Area means an electrical system bounded by interconnections (tie lines), metering and telemetry which controls its generation and/or load to maintain its interchange schedule with other control areas whenever required to do so and contributes to frequency regulation of the synchronously operating system".

In Indian context, the geographical area of a state under the jurisdiction of SLDCs, Inter State Generating Stations (ISGS) and regional entities whose scheduling is coordinated by RLDCs are deemed control areas for the purpose of this procedure.

2.2. "**Net Interchange**" of the Control Area is the algebraic sum of its Imports (+) and Exports (-) with other control areas.

2.3. **"Demand"** means the demand of Active Power in MW.

2.4. **"Frequency response"** is defined as the automatic, sustained change in the power consumption by load or output of generators that occurs immediately after a change in the control area's load-generation balance and which is in a direction to oppose a change in the Interconnection's frequency.

2.5. "**System Inertia**" is the ability of power system to oppose changes in frequency. Physically, it is loosely defined by the mass of all the synchronous rotating generators and motors connected to the system.

2.6. **"Interconnection"** refers to one synchronous system operating at a common frequency. In the Indian context, NEW Grid/Bhutan and Southern Grid would be two interconnections.

2.7. **"Historical Data Recording (HDR)"** refers to the facility to archive and retrieve data at periodic intervals (typically 10 seconds or lower) from the Systems available at each SLDC, RLDC, NLDC or at Generating Station.

3. Frequency Response

During a contingency, such as the tripping of a generator or a loss of load block, the frequency changes due to the mismatch in load and generation. The level to which the frequency drops depends on the starting operating point as well as the system inertia. It is the system inertia, which provides the initial ability of power system to oppose change in the frequency. If the system inertia is high, then the frequency will fall slowly and vice versa, during any system contingency. It is the natural frequency response of a control area, which provides self healing immediately after occurrence of a contingency.
The various sources that contribute to the response of a control area are shown in the resources pyramid (Figure-1).

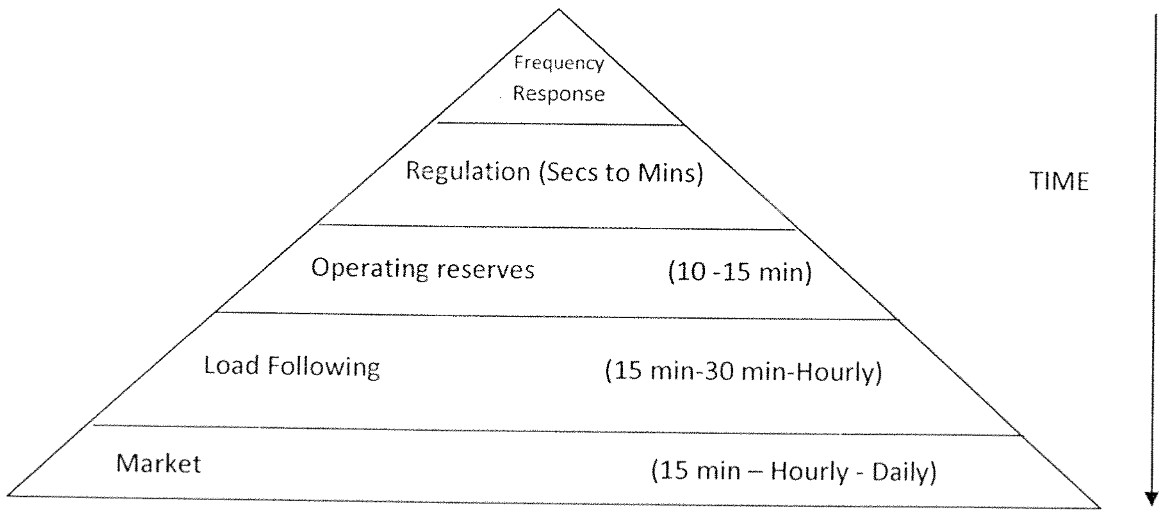


Figure-1: Frequency Response

Frequency response is an inherent property of the system and influences the interconnection frequency change post-contingency and well before any secondary actions, manual or automatic take place. In Indian context, a change in frequency post-contingency provides a price signal to all generators in the system through the frequency linked Unscheduled Interchange (UI) mechanism. The generators may respond to these price signals & vary their generation accordingly. This could happen over the next few minutes (commonly known as secondary response) or over the next half-hour (commonly known as tertiary response. As tight control on net interchange of a control area is not mandated, it can be stated that secondary control is absent by design in the Indian power system. Primary response is however mandated as per the Indian Electricity Grid Code (IEGC). There are two groups of resources which contribute to the frequency response namely load response and governor response of generators.

3.1. Load Response:

Loads also respond to these frequency fluctuations though in an uncontrolled fashion. In general, loads can be grouped into two major categories: motoring loads and non-motoring loads. A Motor load in particular is affected by frequency. When a frequency drops, the motors slow down and they produce less work and therefore consume less energy. Typically for rotating loads such as motors, a 1% change in frequency leads to a 3% change in load [load being approximately proportional to cube of frequency] i.e., a 1.0 Hz change in frequency (2 % of 50 Hz) leads to the motor load changing by 6%. (Source: NERC Training Document Understand and Calculate Frequency Response). However lighting loads such as resistive (non-motoring) are insensitive to frequency.

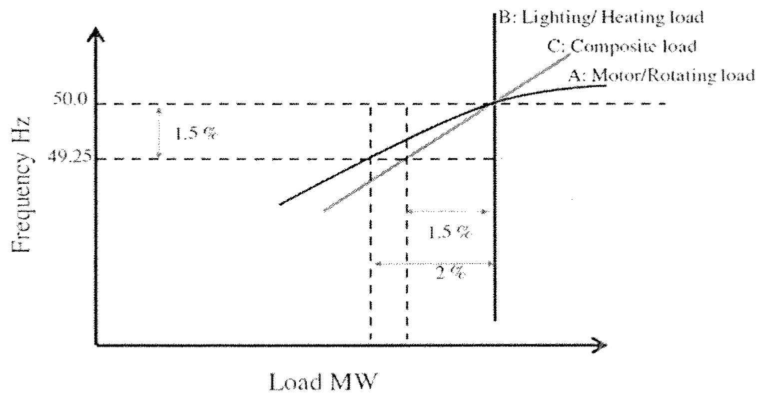


Figure-2: Load Characteristics with 5% droop

The total load in the grid comprise of different kind of load and thus the frequency behavior of the load would depend on the composition of load viz. rotating and non-rotating. Frequency response from loads is declining and has been a cause for concern world-wide. Primary reason for the same is a reduction in industrial load (comprising rotating motor loads) over the years. The modern variable speed drives installed also do not provide the traditional load rejection. In India also there has been a gradual reduction in industrial load. Extract from the Economic Survey 2010-11 is indicated in Table 1 below.

Table 1: Percentage electricity consumption across different sectors in India over the years

1.25 : PATTERN OF ELECTRICITY CONSUMPTION (UTILITIES)

(per cent)

Year	Domestic	Commercial	Industry	Traction	Agriculture	Others
1	2	3	4	5	6	7
1950-51	12.6	7.5	62.6	7.4	3.9	6.0
1960-61	10.7	6.1	69.4	3.3	6.0	4.5
1970-71	8.8	5.9	67.6	3.2	10.2	4.3
1980-81	11.2	5.7	58.4	2.7	17.6	4.4
1981-82	11.6	5.8	58.8	2.8	16.8	4.2
1982-83	12.7	6.1	55.4	2.8	18.6	4.4
1983-84	12.9	6.4	55.8	2.6	17.8	4.5
1984-85	13.6	6.1	55.2	2.5	18.4	4.2
1985-86	14.0	5.9	54.5	2.5	19.1	4.0
1986-87	14.2	5.7	51.7	2.4	21.7	4.3
1987-88	15.2	6.1	47.5	2.5	24.2	4.5
1988-89	15.5	6.2	47.1	2.3	24.3	4.6
1989-90	16.9	5.4	46	2.3	25.1	4.3
1990-91	16.8	5.9	44.2	2.2	26.4	4.5
1991-92	17.3	5.8	42.0	2.2	28.2	4.5
1992-93	18.0	5.7	40.9	2.3	28.7	4.4
1993-94	18.2	5.9	39.6	2.3	29.7	4.3
1994-95	18.5	6.1	38.6	2.3	30.5	4.0
1995-96	18.7	6.1	37.8	2.3	30.9	4.2
1996-97	19.7	6.2	37.2	2.4	30.0	4.5
1997-98	20.3	6.5	35.4	2.3	30.8	4.7
1998-99	21.0	6.4	33.9	2.4	31.4	4.9
1999-00	22.2	6.3	34.8	2.6	29.2	4.9
2000-01	23.9	7.1	34.0	2.6	26.8	5.6
2001-02	24.7	7.5	33.3	2.5	25.3	6.7
2002-03	24.6	7.5	33.9	2.6	24.9	6.5
2003-04	24.9	7.8	34.5	2.6	24.1	6.1
2004-05	24.8	8.1	35.6	2.5	22.9	6.1
2005-06	24.3	8.7	36.8	2.4	21.9	5.9
2006-07	24.4	8.8	37.6	2.4	21.7	5.1
2007-08	24.0	9.2	37.5	2.2	20.6	6.5
2008-09	24.7	10.2	37.1	2.2	20.4	5.4

Source : Ministry of Power/Central Electricity Authority

From Table 1 it would be seen that the electricity consumption across industry, traction and agricultural (which would be mainly rotating loads) has fallen from 73.9% in 1950-51 to 59.7% in 2008-09.

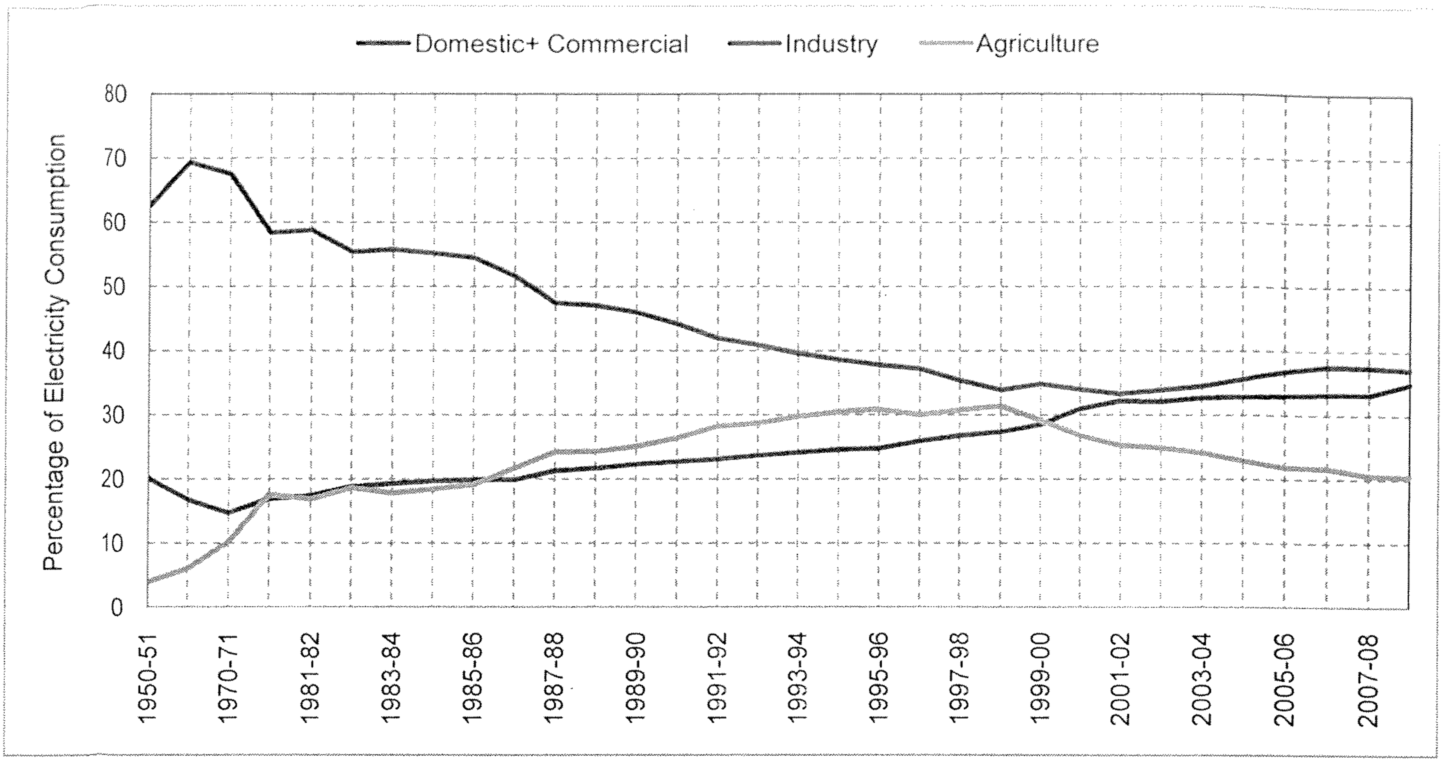


Figure-3: Pattern of Electricity Consumption

In contrast, the domestic and commercial consumption has increased from 20.1% in 1950-51 to 34.9% in 2008-09. There is an increasing trend in all silicon load (electronic devices) component not only in the domestic and commercial segments but also in the industry. These electronic loads do not provide the desired frequency response. This has a bearing on the frequency response from loads. Thus a frequency response of around 3-4% per Hz could be expected from loads due to its inherent nature.

On the other hand, decrease in the System Inertia is also contributing to the decline in the frequency response. Inertia is the stored rotating energy in the system. Physically, it may loosely be defined by the mass of all the synchronous rotating generators and motors connected to the system.

The inertia constant 'H' for rotating machines is denoted by

$$H = \frac{\frac{1}{2} J w^2}{MVA}$$

Where, J = combined inertia of the generator and turbine

w = rated angular velocity in mechanical radians per second.

Following a contingency, the higher system inertia (assuming no frequency response) the longer it takes to reach a new steady state operating frequency i.e., frequency falls slowly. Directly connected synchronous generators and Induction generators will contribute directly to system inertia. A trend in decline of system inertia on account of new generator designs having less inertia and increasing renewable resources are contributing to the decline in the frequency response.

Source	210 MW Singrauli-I	500 MW Singrauli-II	800 MW CGPL-I	Dehar Hydro	Nathpa Jhakri
Machine Rating (MW)	210	500	830	165	250
Rated MVA	247	588	960	173.7	278
Inertia Constant 'H' (Sec)	2.73	3	**2.71**	4.56	4

From the above table it would be observed that inertia constant of 830 MW thermal generator commissioned in March 2012 is less than 500 MW thermal generating units commissioned in mid 1980s. Likewise a 250 MW hydro generator commissioned in 2003 has less inertia constant than a unit commissioned in early eighties.

The issue of inertia is particularly important for high wind power penetration levels in synchronized systems. Most of the wind turbine generators are Standard variable speed wind turbines which are connected to the grid based on non-synchronous interfaces, e.g. power electronic converters. This gives variable speed wind turbines virtually zero inertia in power systems.

3.2. Generator Response:

As per regulation 5.2.(f) of IEGC

"All thermal generating units of 200 MW and above and all hydro units of 10 MW and above, which are synchronized with the grid, irrespective of their ownership, shall have their governors in operation at all times in accordance with the following provisions:

Governor Action

i) Following Thermal and hydro (except those with upto three hours pondage) generating units shall be operated under restricted governor mode of operation with effect from the date given below:

a) Thermal generating units of 200 MW and above,

1) Software based Electro Hydraulic Governor (EHG) system: 01.08.2010

2) Hardware based EHG system 01.08.2010

b) Hydro units of 10 MW and above 01.08.2010

ii) The restricted governor mode of operation shall essentially have the following features:

a) There should not be any reduction in generation in case of improvement in grid frequency below 50.2 Hz. (for example if grid frequency changes from 49.3 to 49.4 Hz. Then there shall not be any reduction in generation). Whereas for any fall in grid frequency, generation from the unit should increase by 5% limited to 105 % of the MCR of the unit subject to machine capability.

b) Ripple filter of +/- 0.03 Hz. shall be provided so that small changes in frequency are ignored for load correction, in order to prevent governor hunting.

c) If any of these generating units is required to be operated without its governor in operation as specified above, the RLDC shall be immediately *advised about the reason and duration of such operation. All governors shall have a droop setting of between 3% and 6%.*

d) After stabilization of frequency around 50 Hz, the CERC may review the above provision regarding the restricted governor mode of operation and free governor mode of operation may be introduced.

iii) All other generating units including the pondage upto 3 hours Gas turbine/Combined Cycle Power Plants, wind and solar generators and Nuclear Power Stations shall be exempted from Sections 5.2 (f) ,5.2 (g), 5.2 (h) and ,5.2(i) till the Commission reviews the situation".

All generators have some type of governor control. The governor senses a change in speed and regulates the energy to be delivered to the generator's prime mover. The changes in the generator output (MW) are in response to the change in frequency and occurs in the 3-10 seconds time frame. Primary response is responsible for the initial arrest of frequency variations.

System Protection Schemes (SPS), Under frequency and df/dt relay operation occurs in the millisecond time frame, even before the primary response comes into play.

3.2.1. Generator Droop

The ratio of frequency deviation to change (in per unit terms) in power output (in per unit terms) is defined as droop. What actually decides governor response is the generator's "droop setting." This is the governor function that dictates the relationship between speed and power output. As per Regulation 5.2 (f) of Indian Electricity Grid Code (IEGC), all thermal units of 200 MW & above and all hydro units of 10 MW and above (except those up to three hours pondage), which are synchronized with the Grid, irrespective of their ownership shall have a droop setting between 3% and 6%.

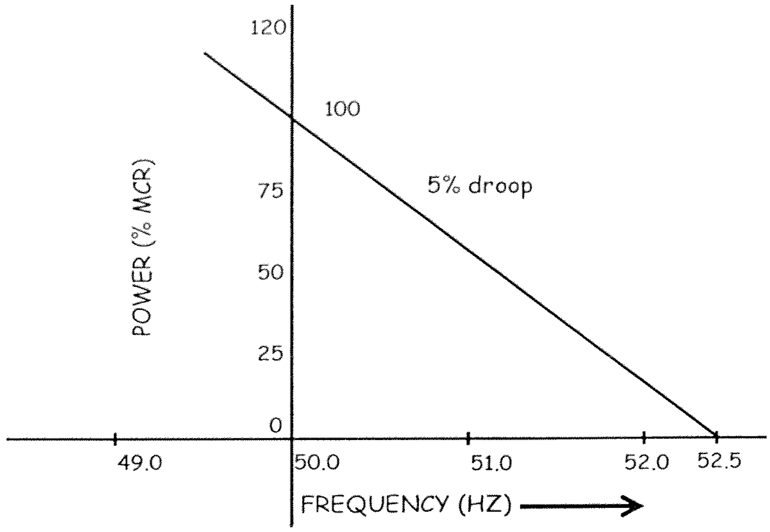


Figure-4: Generator Characteristics with 5% droop

For example, a 5% droop or regulation means that a 5% (2.5 Hz) frequency deviation causes 100% change in power output. That is, for a unit operating at 50 Hz and full load, a 2.5 Hz rise in frequency would cause the governor to attempt to take the unit to no load.

3.2.2. Deadband

Dead_band is the minimum amount of frequency change a governor must see before it starts to respond. As per the regulation 5.2.(f) of IEGC, "*Ripple filter of +/- 0.03 Hz. shall be provided so that small changes in frequency are ignored for load correction, in order to prevent governor hunting*".

4. Control Area Wise Frequency Response

4.1. India follows a decentralized philosophy in which functions like scheduling, accounting, monitoring and control follow a hierarchical structure. Demand estimation, demand management, load generation balance, scheduling etc. are being carried out on control area basis by State Load Despatch Centres (SLDCs). At the regional level, the function is being carried out by Regional Load Despatch Centres (RLDCs). The National Load Despatch Centre (NLDC) is the apex body at National level which coordinates the load dispatch functions with RLDCs and neighboring countries.

4.2. The national installed generating capacity as on 30th April 2012 is of the order of 201 GW with nearly 1800 generating units. The power system in India has been demarcated into smaller control areas for monitoring and control. A control area has its own generator or group of generators and it is responsible for its own load and scheduled interchange with neighboring areas. Each control area contains different kinds of uncertainties and various disturbances due to increased complexity, changing power system structure like sudden load/generation loss. Because of interconnectivity of control areas through tie lines any sudden change in load or generation affects the entire system. Therefore, monitoring of frequency response characteristics (FRC) at control area level is most suitable as it gives a good idea about the frequency response of the Control Area.

4.3. Annexure-1(A) gives the details of the Control Areas under jurisdiction of each RLDC/NLDC.

4.4. Annexure-1(B) gives similar details of Intra State Entities for a typical state for which FRC would be worked out by the SLDCs. Gujarat is taken as example for illustration.

5. Procedure to Calculate Frequency Response Characteristics

5.1. Frequency Response Characteristics (FRC) computations

Frequency Response Characteristics (FRC) will be computed for all events involving a sudden 1000 MW or more load/generation loss or a step change in frequency by 0.50 Hz. The same (FRC) shall be worked out by NLDC, RLDCs and SLDCs to compute each interconnection/region/control area's FRC. Currently, India has large number of 600/660 MW units and this is rapidly increasing. Tripping of one 600/660 MW unit is fairly common. The present maximum size generating unit is 800 MW (UMPP Mundra) and very soon there would be units of 1000 MW size i.e., after commissioning of Kudankulam Nuclear Power Station. Hence 1000 MW change is expected to be an optimal one for the purpose monitoring FRC. Any lower value would lead to more efforts at LDC without commensurate benefit.

The following steps would be followed for computation FRC

(a) After every event involving a sudden 1000 MW or more load/generation loss or a step change in frequency by 0.5 Hz, NLDC would get the PMUs frequency data wherever available, from all the RLDCs. NLDC would also get the exact quantum of load/generation lost from the RLDC of the affected region.

(b) NLDC would plot the frequency graph and determine the initial frequency, minimum/maximum frequency, settling frequency and time points (points A, C and B of the Figure-5). Accordingly frequency difference points & corresponding time to be used for FRC calculations would be informed to all RLDCs.

(c) NLDC would also work out region wise, NEW grid, Southern grid and Neighboring countries (Bhutan and Nepal) FRC (Format FRC-3) based on 10 second or 30 second Historical Data Recording (HDR) data available at NLDC and inform all RLDCs as well as post the same on its website within three (3) working days. RLDCs would inform the SLDCs in their region.

(d) RLDCs shall also work out each control area wise FRC (Format FRC-2) based on HDR data available at RLDCs and post the same on its website within six (6) working days.

(e) All the SLDCs shall work out FRC for all the intrastate entities for events indicated by the Regional Load Despatch Centres based on the HDR data available at their respective SLDCs and post the same on its website within six (6) working days. (Format FRC-1).

(f) In cases where SLDCs do not have any website, the FRC (FRC-1) would be sent to RLDC within one week.

5.2. Input data for FRC:

i. The data for Frequency Response Characteristic Calculations should be taken from the real time telemetered data recorded by the SCADA systems installed at Control Areas / Regional Load Despatch Centres / National Load Despatch Centre.

ii. All control area interconnection (tie) points are expected to be equipped to telemeter MW power flow to respective control center.

iii. Bad quality of data would be flagged / mentioned by the control centre and reasonable assumptions made for FRC computation. Details of these may be mentioned.

iv. In cases of load/generation loss through action of System Protection Schemes (SPS) the exact quantum must be determined so that the FRC computations are correct. SLDCs/RLDCs/NLDC must therefore make efforts to get telemetered data of all such SPS locations.

5.3. Instructions for computation of FRC:

The FRC -1 is the Control Area Frequency Response Characteristic Survey form. A Sample frequency chart is shown in Figure-5 with points A, B, and C labeled. Figure-5 depicts a typical frequency excursion caused by a loss of a large generator on an Interconnection. **Point A** denotes the interconnection frequency immediately before the disturbance. **Point B** represents the Interconnection frequency at the point immediately after the frequency stabilizes due to governor action but before the contingent control area takes any corrective actions, automatic or manual. **Point C** represents the interconnection frequency at its maximum deviation due to the loss of rotating kinetic energy from the interconnection.

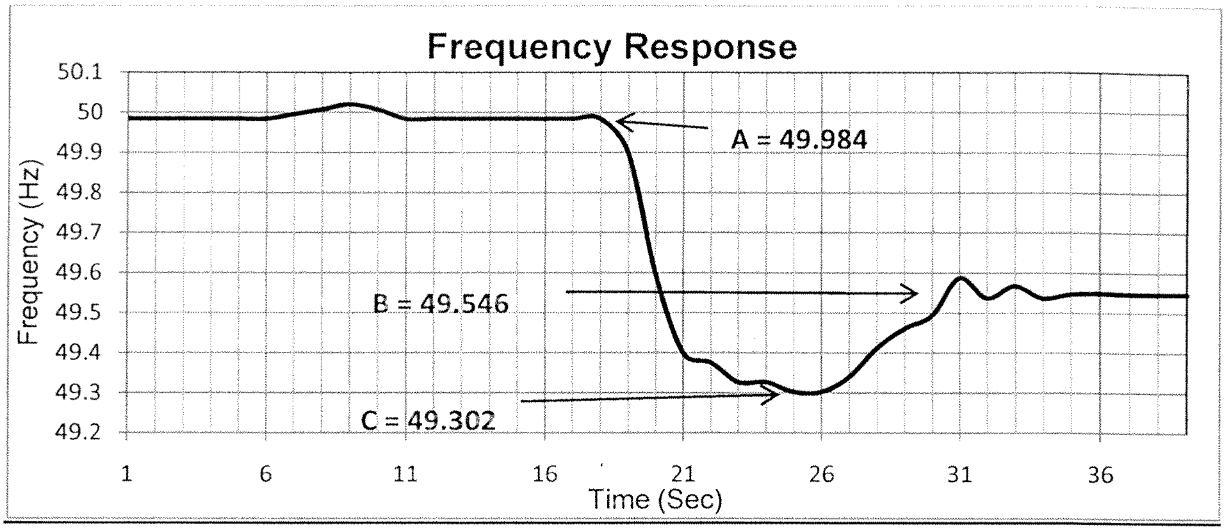


Figure-5: Frequency excursion caused by a loss of a large generator

Guidelines to work out Frequency Response Characteristics of Control Area (FRC - 1) are as follows (Refer FRC-1):-

Step-1 Actual net interchange of the control area immediately before the disturbance (Point - A) = P_A. Sign convention for net power imported into a CONTROL AREA is positive (+) and net power exported out of a control area is negative (-).

Step-2 Actual net interchange of the control area immediately after the disturbance (Point - B) = P_B. Use the same sign Convention as Step-1.

Step-3 The Net interchange of the CONTROL AREA = (P_B - P_A). For a disturbance that causes the frequency to decrease, this value should ideally be negative except for the contingent CONTROL AREA, in which case it is positive and conversely.

Step -4	If the control area has suffered the loss, then Load or generation lost by the control area = P_L. Otherwise, the loss (P_L) is zero. Sign convention for Load Loss is negative (-) and Generation Loss positive (+).
Step-5	The Control Area Response = $\Delta P = (P_B - P_A) - P_L$
Step -6	The Frequency immediately before the disturbance = f_A.
Step -7	The Frequency immediately after the disturbance = f_B.
Step -8	Change in Interconnection Frequency from Point A to Point B = $\Delta f = (f_B - f_A)$
Step -9	Frequency Response Characteristic (FRC) of the Control Area = $\Delta P/\Delta f$
Step -10	Net Demand met by Control Area before the disturbance = P_{DEMAND}
Step -11	Internal Generation of the Control Area before the disturbance = $(P_{DEMAND}-P_A)$.
Step -12	Ideal Load Response assuming 4% per Hz = $P_{Ideal\ Load} = (0.04^*\ P_{DEMAND})$.
Step -13	Assuming 5% droop means 5% (2.5 Hz) change in frequency causes 100% change in generation. So for 1 Hz change in frequency requires (1/2.5)*100% change in generation. Ideal generator Response = $P_{Ideal\ gen} = 0.4^*\ (P_{DEMAND} - P_A)$.
Step -14	Composite Ideal response = $P_{composite} = (P_{Ideal\ Load} + P_{Ideal\ gen})$
Step -15	Percentage Ideal response = $((\Delta P/\Delta f)^*100/\ Pcomposite)$

5.4. FRC Review

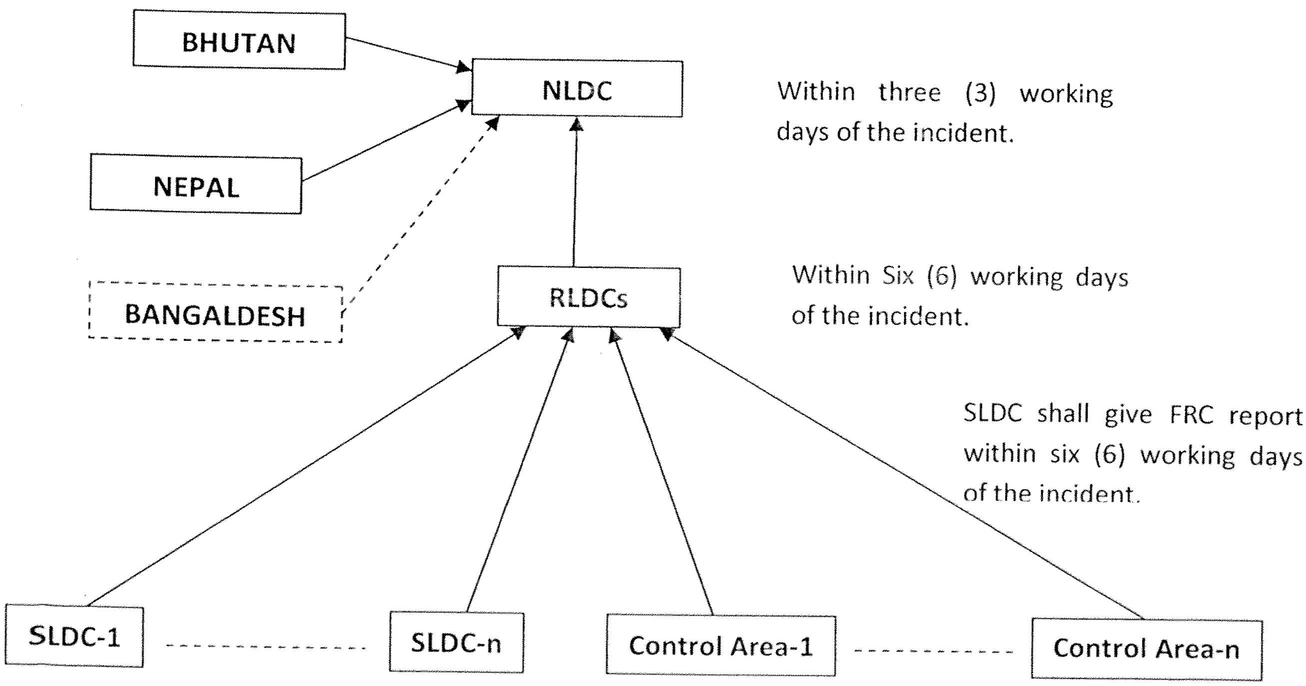
The FRC data received shall be reviewed for uniformity, completeness, and compliance to the instructions. The frequency response for the control areas shall be reviewed periodically (Quarterly or Half-yearly). National Load Despatch Centre shall submit the Frequency Response Characteristics of Control areas/Regions Quarterly to the Commission.

i. NLDC would assess the composite FRC for the five regional grids, Bhutan and Nepal.

ii. RLDCs would assess the composite FRC for the Regional Entity control areas.

iii. SLDCs would assess the composite FRC for intra state entity control areas.

5.5. Duration of submission of Reports



6 - LIMITING FACTORS

The factors affecting the accuracy of the calculation of the FRC are:

a) Identification of the exact point of disturbance and interpretation of the time window to be measured. “Immediately before” and “Immediately after” are subject to interpretation.

b) Limitation of the sampling rate of the data recorded by the SCADA system (normally 10 second samples are available in the SCADA). At times, there is also a loss in part of the telemetered data due to various reasons and this causes inaccuracies. Moreover some of the data points are received through ICCP from Sub-LDC/SLDC to RSCC which imposes an additional time delay.

c) A large number of events must be captured and subjected to statistical treatment before a reasonably accurate figure can be obtained. This is also necessary to rule out the impact of high variability of the load.

d) Both load and generation are continuously changing naturally.

e) System size, generator loading, losses, distance of generators from the point of loss, load composition, number of generators in service at the time of the incident, type of generation, governor action, time of day, season and interconnections with the neighbors significantly influence FRC calculations.

f) SPS, Under frequency relays (UFR) and df/dt relays are installed in all the regions to take care of contingencies. Such actions are in millisecond timeframe and are the first to provide relief by way of load shedding.

FRC -1

STATE LOAD DESPATCH CENTRE

FREQUENCY RESPONSE CHARACTERISTIC (FRC) OF CONTROL AREA

DATE: CONTROL AREA:

EVENT : REGION:

Loss of generation (+)/ Load (-) in MW

Particulars		Dimension	TOTAL STATE	INTRA STATE ENTITY-1	INTRA STATE ENTITY-2
1. Actual net interchange immediately before the disturbance	P_A	MW			
2. Actual net interchange immediately after the disturbance	P_B	MW			
3. Change in Net interchange	$(P_B - P_A)$	MW			
4. Generation Loss (+) / Load Throw off (-) during the Event	P_L	MW			
5. Control Area Response (ΔP)	$(P_B - P_A) - P_L$	MW			
6. Frequency before the Event	f_A	HZ			
7. Frequency after the Event	f_B	HZ			
8. Change in Frequency (Δf)	$(f_B - f_A)$	HZ			
9. Frequency Response Characteristic (FRC)	$\Delta P/\Delta f$	MW/HZ			
10. Net System Demand met before the Event	P_{DEM}	MW			
11. Internal Generation before the Event (P_{gen})	$(P_{DEM} - P_A)$	MW			
12. Ideal load response assuming 4% per Hz ($P_{Ideal\ Load}$)	$0.04^* P_{DEM}$	MW/Hz			
13. Ideal generator response assuming 5% droop ($P_{Ideal\ gen}$)	$0.40^* (P_{DEM} - P_A)$	MW/Hz			
14. Composite ideal response ($P_{composite}$)	$P_{Ideal\ Load} + P_{Ideal\ gen}$	Mw/Hz			
15. Percentage of ideal response	$(\Delta P/\Delta f)^*100/ P_{composite}$	%			

NOTES :

1. Net Power delivered out of a Control Area (Export) is negative (-).
2. Net Power Import of the Control Area (Import) is positive (+).

FRC -2

REGIONAL LOAD DESPATCH CENTRE

FREQUENCY RESPONSE CHARACTERISTIC (FRC) OF REGION

DATE:

EVENT :

Loss of generation (+)/ Load (-) in MW

Particulars	Dimension	Region	Control Area-1	Control Area-2	Control Area-3	Control Area-4	Control Area-5	Control Area-6
1. Actual net interchange immediately before the disturbance (P_A)	MW							
2. Actual net interchange immediately after the disturbance (P_B)	MW							
3. Change in Net interchange (P_B - P_A)	MW							
4. Generation Loss (+) / Load Throw off (-) during the Event (P_L)	MW							
5. Control Area Response ($\Delta P = (P_B - P_A) - P_L$)	MW							
6. Frequency before the Event (F_A)	HZ							
7. Frequency after the Event (f_B)	HZ							
8. Change in Frequency ($\Delta f = f_B - f_A$)	HZ							
9. Frequency Response Characteristic (FRC = $\Delta P/\Delta f$)	MW/HZ							
10. Net System Demand met before the Event (P_{DEM})	MW							
11. Internal Generation before the Event ($P_{gen} = P_{DEM} - P_A$)	MW							
12. Ideal load response assuming 4% per Hz ($P_{Ideal\ Load} = 0.04 * P_{DEM}$)	MW/Hz							
13. Ideal generator response assuming 5% droop ($P_{Ideal\ gen} = 0.40 * (P_{DEM} - P_A)$)	MW/Hz							
14. Composite ideal response ($P_{composite}$) $= P_{Ideal\ Load} + P_{Ideal\ gen}$	Mw/Hz							
15. Percentage of ideal response = (($\Delta P/\Delta f$)*100/ Pcomposite)	%							

NOTES :

1. Net Power delivered out of the Region (Export) is negative (-).
2. Net Power received into the Region (Import) is positive (+).

FRC -3

NATIONAL LOAD DESPATCH CENTRE

FREQUENCY RESPONSE CHARACTERISTICS

DATE & Time of the Event:

EVENT ID: EVENT :

; Loss of Generation(+)/Load(-) in MW

Particulars	Dimension	INDIA	NEW GRID	SR GRID	NR	ER	WR	NER	BHUTAN
1. Actual net interchange immediately before the disturbance (P_A)	MW								
2. Actual net interchange immediately after the disturbance (P_B)	MW								
3. Change in Net interchange (P_B - P_A)	MW								
4. Generation Loss (+) / Load Throw off (-) during the Event (P_L)	MW								
5. Control Area Response ($\Delta P = (P_B - P_A) - P_L$)	MW								
6. Frequency before the Event (f_A)	HZ								
7. Frequency after the Event (f_B)	HZ								
8. Change in Frequency ($\Delta f = f_B - f_A$)	HZ								
9. Frequency Response Characteristic (FRC = $\Delta P/\Delta f$)	MW/HZ								
10. Net System Demand met before the Event (P_{DEM})	MW								
11. Internal Generation before the Event ($P_{gen} = P_{DEM} - P_A$)	MW								
12. Ideal load response assuming 4% per Hz ($P_{Ideal\ Load} = 0.04 * P_{DEM}$)	MW/Hz								
13. Ideal generator response assuming 5% droop ($P_{Ideal\ gen} = 0.40 * (P_{DEM} - P_A)$)	MW/Hz								
14. Composite ideal response ($P_{composite}$) = $P_{Ideal\ Load} + P_{Ideal\ gen}$	Mw/Hz								
15. Percentage of ideal response = (($\Delta P/\Delta f$)*100/ Pcomposite)	%								

NOTES :

1. Net Power delivered out of the Region (Export) is negative (-).
2. Net Power received into the Region (Import) is positive (+).

Annexure-I

A. **Regions under Jurisdiction of NLDC:** (As on July-2012)

Northern Region, Eastern Region, Western Region, Northeastern Region, Southern Region, Bhutan and Nepal.

B. **Control Areas Under Jurisdiction of RLDCs**

Control Areas Under Jurisdiction of RLDCs							
NRLDC		31	Salal	16	Lanco Pathadi	6	Nagaland
1	Punjab	32	Bairasiul	17	KAWAS	7	Tripura
2	Haryana	33	Tanakpur	18	GANDHAR	8	AGBPP
3	Rajastan	34	Dhauliganga	19	SSP	9	AGTPP
4	Delhi	35	Dulhasti	20	CGPL	10	Khandong
5	Uttar Pradesh	36	Sewa-II	21	RGPPL	11	Kopili
6	Uttarkhand	37	AD Hydro	22	TAPS	12	Doyang
7	Chandigarh	38	Karcham Wangtoo	23	KAPP	13	RHEP
8	Himachal Pradesh	39	Malana-2	**ERLDC**		14	Loktak
9	Jammu & Kashmir	40	Tehri	1	Bihar	**SRLDC**	
10	Singrauli	41	Koteswar	2	Jharkhand	1	Andhra Pradesh
11	Rihand-1	42	Jhakri	3	DVC	2	Karnataka
12	Rihand-2	43	BBMB complex	4	Orissa	3	Kerala
13	Dadri-1	44	Dehar	5	West Bengal	4	Tamilnadu
14	Dadri NCR	45	Pong	6	FSTPP*	5	Puducherry
15	Unchahar	**WRLDC**		7	KhSTPP1	6	Ramagundam-NTPC
16	Dadri-Gas	1	Gujarat	8	KhSTPP2	7	Simhadri-NTPC
17	Anta	2	Maharastha	9	TSTPS-I	8	Neyveli-II
18	Auraiyya	3	Madhya Pradesh	10	TSTPS-II (SR)	9	Neyveli-I Exp
19	Badarpur	4	Chattisgarh	11	MPL	10	Kaiga
20	Tanda	5	Goa	12	Sterlite	11	MAPS
21	Faridabad Gas	6	DD	13	Teesta		
22	NAPS	7	DNH	14	RHEP		
23	RAPP-B	8	KSTPS Stage-I	15	THPS		
24	RAPP-C	9	KSTPS Stage-II	16	CHPS		
25	RAPP-A	10	VSTPS Stage-I	**NERLDC**			
26	Jhajjar	11	VSTPS Stage-II	1	Arunachal Pradesh		
27	Sree Cement	12	SIPAT Stage-I	2	Assam		
28	Chamera-1	13	SIPAT Stage-II	3	Manipur		
29	Chamera-2	14	NSPCL	4	Meghalaya		
30	Uri-1	15	JPL,TAMNAR	5	Mizoram		

Intra state entities in Gujarat under SLDC's jurisdiction for which FRC would be computed by SLDC					
1	DGVCL	11	GIPCL-1	35	UTCL,KOVAYA
2	MGVCL	12	GICPL-2	36	LBC
3	PGVCL	13	GSEG(H)	37	GALLANT METAL
4	UGVCL	14	SLPP(M)	38	WELSPUN
5	TPL-SECo	15	SLPP(M) - II	39	HINDALCO
6	TPL-AECo	16	GPEC	40	VARSANA ISPAT
7	TEL, SEZ, Dahej	17	ESSAR	41	GFL, DAHEJ
8	KPTL	18	ALTPS	42	PCBL, MOKHA
9	MPSEZ UPL, Mundra	19	TPL-SUGEN	43	Shreeyam P&S ind. Ltd
10	**GSECL**	20	APL (1-4)	44	RIL DAHEJ
10.1	DGBPS-1	21	APL-II (5 & 6)	45	Essar CPP (31 MW)
10.2	DGBPS-2	22	APL-III (7 & 8)	46	J K Paper Ltd
10.3	UTPS	23	EPGL, Vadinar	47	Solaries Ltd
10.4	WTPS(1-6)	24	GSEG (H)-2	48	Amreli Biomass
10.5	WTPS-7	25	AML	49	Junagadh Biomass
10.6	GTPS(1-4)	26	GACL	50	Saurastra Cemen
10.7	GTPS-5	27	ONGC(A)	51	Rama News
10.8	KLTPS	28	ONGC(H)	52	Bhavnagar Biomass
10.9	KLTPS	29	PCBL, PALEJ	53	Shree Renuka
10.1	STPS	30	SAL	54	Essar Oil Ltd
10.11	UGPP - I	31	UPL	55	Nirma Ltd (Kalatalav)
10.12	UGPP - II	32	ESSAR CPP (BPoL)		
10.13	UHPS	33	RIL		
10.14	KHPS	34	JINDAL SAW LTD		

Annexure-2

Illustrative Example for Calculation of FRC

The example explains about how to calculate Frequency Response Characteristics of a Region. In this example Southern Region is taken for Illustrative Purpose only.

Event: At 1748 hours on 01st May 2012, Pole-1 of Talcher–Kolar HVDC bipole got blocked due to HVDC line fault. The bipole was carrying 1976 MW from the NEW grid (Talcher) to Southern grid (Kolar). The Pole-2 came on Ground return mode and power came down to 125 MW.

During this tripping, SPS operated at Kolar end resulting in load throw off or load loss of 990MW in Southern region i.e.., Andhra Pradesh – 223 MW, Karnataka – 350 MW, Kerala- 0 MW, Tamilnadu – 417 MW and Pondicherry- 0 MW.

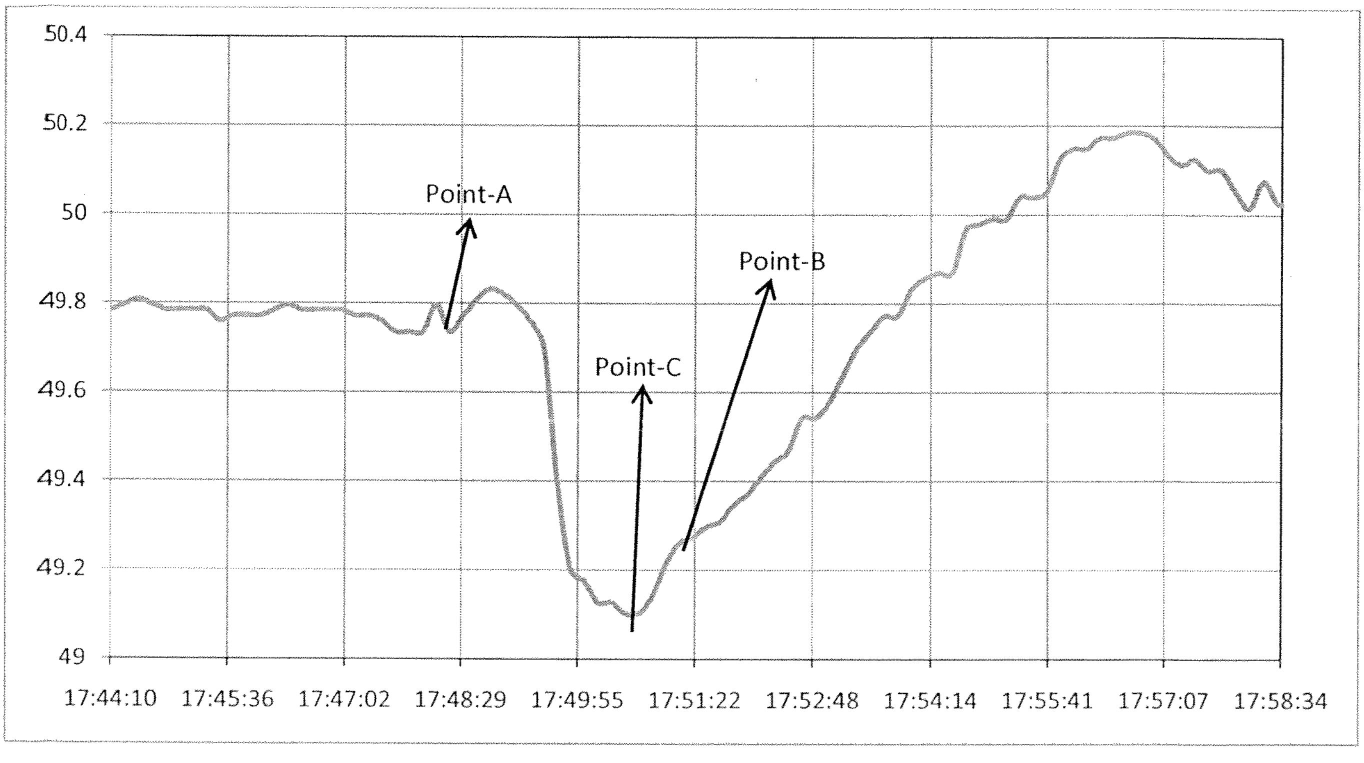


Figure-A: Frequency of Southern Region during Tripping of Talcher-Kolar Pole-1

From the Figure-A, it can be noted that,

Start Time (Point-A) = 17:48:20; Frequency = f_A =49.74 Hz.

End Time (Point-B) = 17:51:10; Frequency = f_B = 49.26 Hz

Sign Conventions:

- Sign convention for net power into a Control Area (Import) is positive (+)
- Sign convention net power out of a Control Area (Export) is negative (-).
- Sign convention for Load Loss/Load Throw off is negative (-)
- Sign convention for Generation Loss positive (+).

TIME	SR FREQ	T-K FLOW	GAZUWAKA FLOW	BHADRWATI	SR Import	
17:47:30	49.75976563	1979	109	701	2789	
17:47:40	49.73535156	1979	109	701	2789	
17:47:50	49.73535156	1979	109	701	2789	
17:48:00	49.73535156	1976	109	701	2786	
17:48:10	49.79589844	1976	109	701	2786	
17:48:20	**49.73535156**	**1976**	**109**	**701**	**2786**	**Point-A**
17:48:30	49.77148438	1197	109	701	2007	
17:48:40	49.80761719	1197	109	701	2007	
17:48:50	49.83203125	1208	109	701	2018	
17:49:00	49.8203125	1220	109	701	2030	
17:49:10	49.79589844	1220	109	701	2030	
17:49:20	49.75976563	1220	109	701	2030	
17:49:30	49.69824219	1026	109	701	1836	
17:49:40	49.39453125	1026	109	701	1836	
17:49:50	49.20019531	821	109	701	1631	
17:50:00	49.17578125	125	109	701	935	
17:50:10	**49.12695313**	**125**	**109**	**701**	**935**	**Point-C**
17:50:20	49.12695313	114	109	701	925	
17:50:30	49.10253906	114	109	701	925	
17:50:40	49.10253906	117	109	701	927	
17:50:50	49.13964844	117	109	705	931	
17:51:00	49.21191406	117	144	705	966	
17:51:10	**49.26074219**	**117**	**144**	**705**	**966**	**Point-B**
17:51:20	49.2734375	121	144	705	970	
17:51:30	49.296875	121	144	705	970	
17:51:40	49.30957031	117	144	701	962	
17:51:50	49.34570313	117	144	701	962	
17:52:00	49.37011719	117	144	701	962	
17:52:10	49.40722656	117	144	701	962	
17:52:20	49.44335938	123	144	701	968	
17:52:30	49.46777344	123	144	701	968	

Table-2: SCADA data for Talcher-Kolar Pole-2 tripping on 01.05.2012

Step -1 Actual net interchange of Southern Region immediately before the disturbance i.e., Point – A (start time = 17:48:20) = P_A = 2786 MW.

Step -2 Actual net interchange of Southern Region immediately after the disturbance i.e., at Point – B (End time = 17:51:10) = P_B = 966 MW.

Step -3 The Net interchange of Southern Region= (P_B - P_A) = 966-2786 = -1820 MW.

Step -4 Due to SPS action there was a load throw off of 990 MW. So, Load throw off of Southern Region = P_L = -990 MW.

Step -5 Southern Region Response = ΔP = (P_B - P_A) - P_L = (966-2786) - (-990) = -830 MW.

Step -6 The Frequency immediately before the disturbance = f_A =49.74 Hz.

Step -7 The Frequency immediately after the disturbance = f_B = 49.26 Hz.

Step -8 Change in Frequency from Point A to Point B = Δf = (f_B - f_A) =(49.26-49.74) = -0.48 Hz.

Step -9 Frequency Response Characteristic (FRC) of Southern Region = $\Delta P/\Delta f$ = (-830)/(-0.48) =1729 MW/Hz

Step -10 Net Demand met by Southern Region before the disturbance i.e., Point – A (start time = 17:48:20) = P_{DEMAND} = 23728 MW.

Step -11 Internal Generation of Southern Region before the disturbance i.e., at Point – A (Start time = 17:48:20) = P_{DEMAND} - P_A. = (23728-2786) = 20942MW.

Step -12 Ideal Load Response of Southern Region assuming 4% per Hz = $P_{Ideal\ Load}$ = (0.04* (23728-990)) =909.52 MW/Hz.

Step -13 Assuming 5% droop means 5%; Ideal generators Response of Southern Region = $P_{Ideal\ gen}$ = 0.4* (23728-2786) = 0.4*20942 = 8376.80 MW/Hz.

Step -14 Composite Ideal response = $P_{composite}$ = ($P_{Ideal\ Load}$ + $P_{Ideal\ gen}$)= (909.52+8376.80) = 9286 MW/Hz.

Step -15 Percentage Ideal response = (($\Delta P/\Delta f$)*100/ Pcomposite) = ((-830/-0.48)*100/ 9286) =18.62%.

Step by step procedure shown above is summarized in the Table-3:

Particulars		Dimension	Southern Region
1. Actual net interchange immediately before the disturbance	P_A	MW	2786
2. Actual net interchange immediately after the disturbance	P_B	MW	966
3. Change in Net interchange	$(P_B - P_A)$	MW	-1820
4. Generation Loss (+) / Load Throw off (-) during the Event	P_L	MW	-990
5. Control Area Response (ΔP)	$(P_B - P_A) - P_L$	MW	-830
6. Frequency before the Event	f_A	HZ	49.74
7. Frequency after the Event	f_B	HZ	49.26
8. Change in Frequency (Δf)	$(f_B - f_A)$	HZ	-0.48
9. Frequency Response Characteristic (FRC)	$\Delta P/\Delta f$	MW/HZ	1729
10. Net System Demand met before the Event	P_{DEM}	MW	23728
11. Internal Generation before the Event (P_{gen})	$(P_{DEM} - P_A)$	MW	20942
12. Ideal load response assuming 4% per Hz ($P_{Ideal\ Load}$)	$0.04^* P_{DEM}$	MW/Hz	910
13. Ideal generator response assuming 5% droop ($P_{Ideal\ gen}$)	$0.\ 4^* (P_{DEM} - P_A)$	MW/Hz	8377
14. Composite ideal response ($P_{composite}$)	$P_{Ideal\ Load} + P_{Ideal\ gen}$	Mw/Hz	9286
15. Percentage of ideal response	$(\Delta P/\Delta f)^*100/ P_{composite}$	%	18.62%

Table-3: Summary of FRC of Southern Region for Talcher-Kolar Pole-1 tripping