Post Synchronization Experience in Indian Grid

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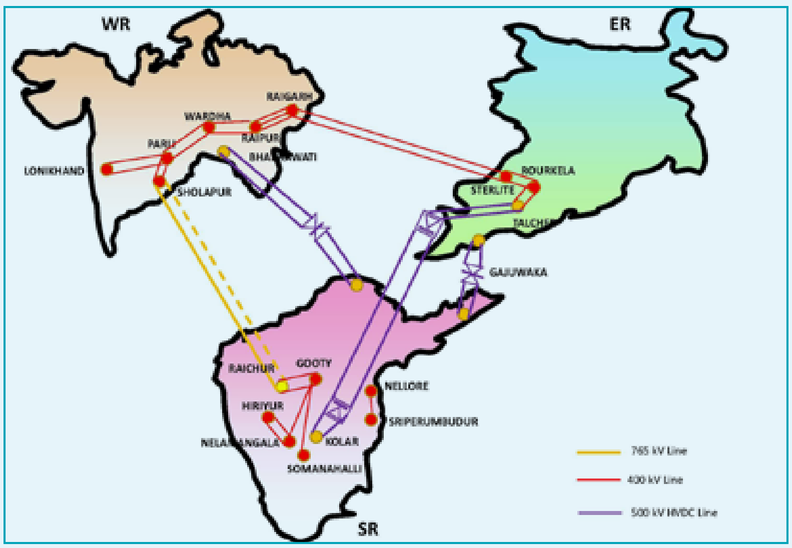
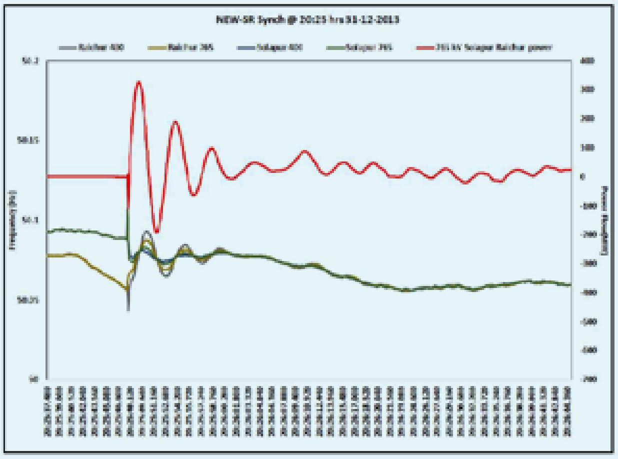


NEW-SR GRID SYNCHRONIZATION EVENTS

From date	From Time	To Date	To Time	Number of hours of synchronous operation	Reason for Loss of Synchronization	Remarks
31.12.2013	20:25	02.01.2014	05:32	33:07	Tripping of 765 kV Sholapur-Raichur line on over current protection	SPS signal not received at Jindal/KSK
02.01.2014	20:23	04.01.2014	18:25	46:02	765/400 kV ICT trip at Raichur	
05.01.2014	10:41	05.01.2014	12:54	02:13	765/400 kV ICT trip at Raichur	
07.01.2014	17:54	07.01.2014	21:30	03:36	Tripping of 765 kV Sholapur-Raichur line on over current protection after loss of HVDC Bhadravati BTB carrying 250 MW	436 MW gen loss at JPL 240 MW gen loss at KSK 200 MW load shed in SR
08.01.2014	19:56	10.01.2014	07:31	35:35	Desynchronized to facilitate Planned SD of HVDC Talcher-Kolar	
14.01.2014	11:53	Till date	-	-	-	-

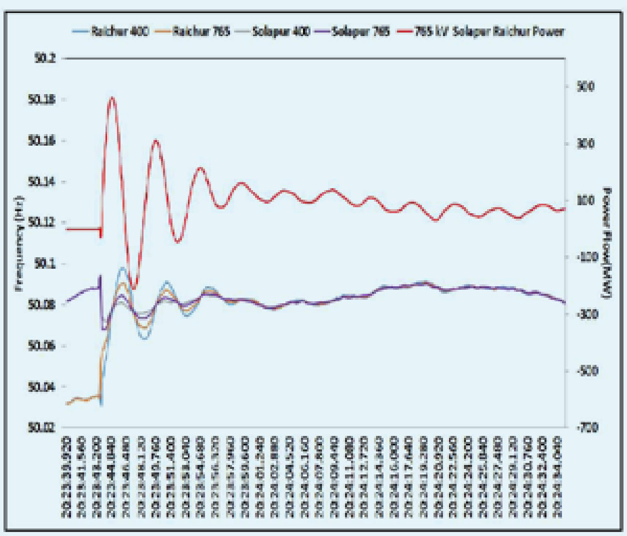
FIRST SYNCHRONIZATION 31-12-13 20:25 HRS



First Synchronization Features:

- Frequency of NEW Grid higher than SR Grid.
- SR Frequency : 50.057 Hz
- NEW Frequency: 50.096 Hz
- Δf = NEW-SR = 0.039 Hz
- Δδ =Raichur-Solapur= 0.098o
- Max Power flow in First swing*: 328 MW Export from NEW Grid to SR Grid.
- Oscillation Mode : 0.21 Hz
- Oscillation damped out time : 16 sec

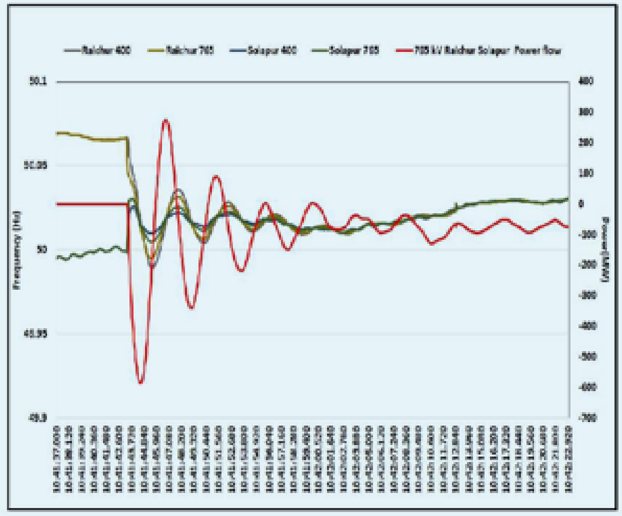
SECOND SYNCHRONIZATION 02-01-2014 20:23 HRS



Second Synchronization Features

- Frequency of NEW Grid higher than SR Grid.
- SR Frequency : 50.035 Hz
- NEW Frequency: 50.087 Hz
- Δf = NEW-SR = 0.052 Hz
- Δδ =Raichur-Solapur= - 0.929o
- Max Power flow in First swing* : 549 MW Export from NEW grid to SR Grid.
- Oscillation Mode : 0.21 Hz
- Oscillation damped out time : 23 Sec

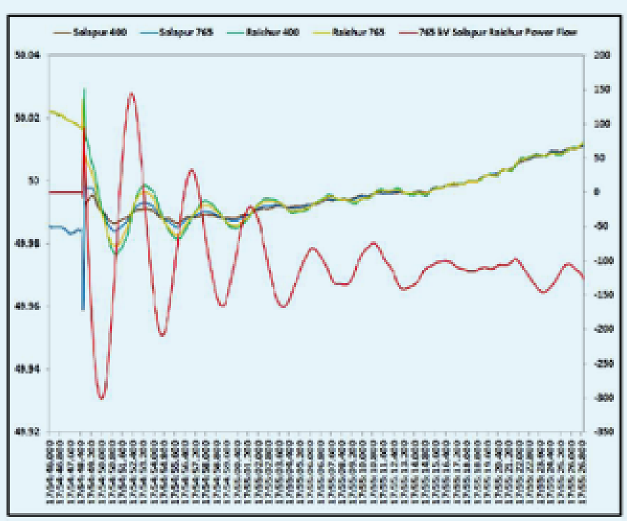
THIRD SYNCHRONIZATION 05-01-2014 10:41 HRS



Third Synchronization Features:

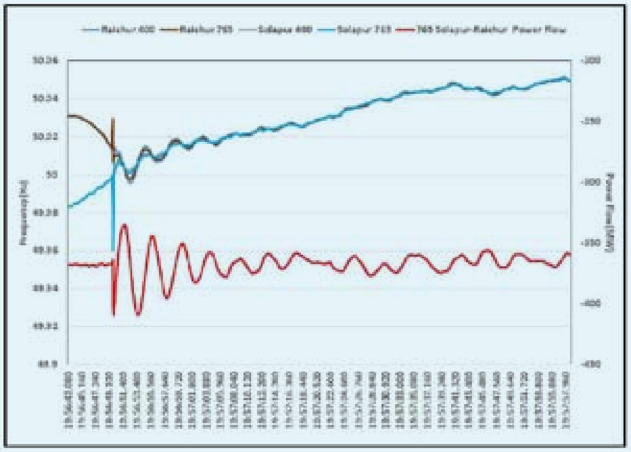
- Frequency of SR Grid higher than NEW Grid.
- SR Frequency : 50.064 Hz
- WR Frequency: 49.998 Hz
- Δf = NEW-SR = - 0.066 Hz
- Δδ =Raichur-Solapur= 2.763o
- Max Power flow in First swing*: 585 MW export from SR to NEW Grid.
- Oscillation Mode : 0.21 Hz
- Oscillation damped out time : 25 sec

FOURTH SYNCHRONIZATION 07-01-2014 17:54 HRS



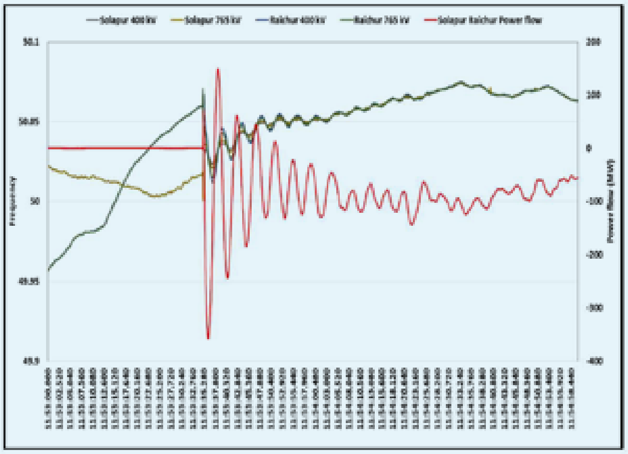
- Frequency of NEW Grid higher than SR Grid.
- SR Frequency : 50.017 Hz
- NEW Frequency: 49.985 Hz
- Δf = NEW-SR = - 0.032 Hz
- Δδ =Raichur-Solapur = -0.518o
- Max Power flow in First swing*: 335 MW Export from SR Grid to NEW Grid.
- Oscillation Mode : 0.21 Hz
- Oscillation damped out time : 27 sec

FIFTH SYNCHRONIZATION 08-01-2014 19:56 HRS



- Fifth Synchronization Features:
- Frequency of SR Grid higher than NEW Grid.
- SR Frequency : 50.013 Hz
- NEW Frequency: 50.000 Hz
- Δf = NEW-SR = -0.013 Hz
- Δδ =Raichur-Solapur= - 4.43 o
- Max Power flow in First swing*: 409 MW Export from SR Grid to NEW Grid.
- Oscillation Mode : 0.21 Hz
- Oscillation damped out time : 31 sec

SIXTH SYNCHRONIZATION 14-01-2014 11:53 HRS

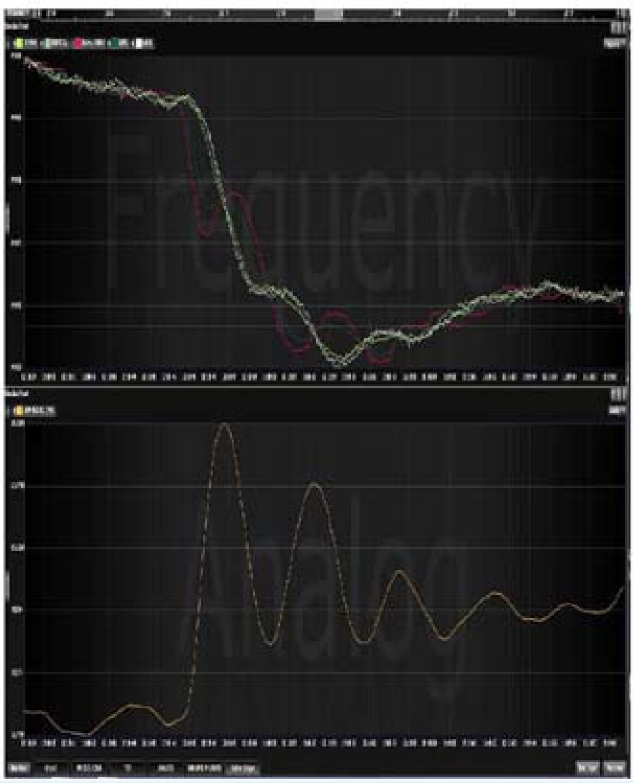


- Sixth Synchronization Features:
- Frequency of SR Grid higher than NEW Grid.
- SR Frequency : 50.059 Hz
- NEW Frequency: 49.793 Hz
- Δf = NEW-SR = - 0.041 Hz
- Δδ =Raichur-Solapur= 1.60o
- Max Power flow in First swing*: 358 MW Export from SR Grid to NEW Grid.
- Oscillation Mode : 0.21 Hz
- Oscillation damped out time : 51 sec

UNIT TRIPPING IN SR

Unit Tripping in Southern Grid

Kudankulam Unit Outage

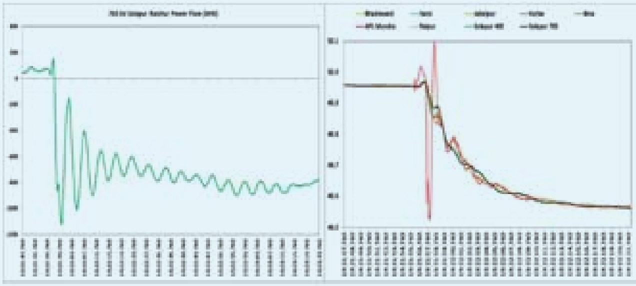


- Kudankulam (1000) MW was withdrawn at 12:03 Hrs on 03-01-14,
- Generation was around 290 MW.
- 765 kV Solapur Raichur line power flow changed from 15 MW export to SR to 283 MW import to SR Grid
- It settled at 92 MW Export to SR grid after 18 seconds.
- The frequency came down from 49.99 Hz to 49.91 Hz.

UNIT TRIPPING IN WR

Large Disturbance

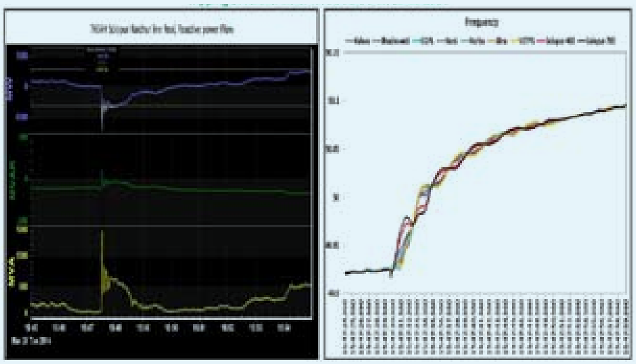
Loss of (3800 MW) CGPL UMPP Power Plant and df/dt load shedding operation on 12-03-2014



- Oscillation of 0.2 Hz in Power flow of 765 kV Solapur Raichur which died out in 80 seconds.

TRIPPING OF HVDC POLE CONNECTING NEW AND SR GRID

Large Disturbance Tripping of Talcher Kolar HVDC Pole 1 on 25-03-2014



- Maximum power Flow in the first swing was 1387 MW from SR to WR which reduced to 860 MW in the next swing.
- Oscillation of 0.2 Hz died out in 23 second

EXPERIENCE

- 0.2 Hz Inter Area oscillation is being observed in the Grid post synchronization.
- Any tripping and sudden large load/generation change in SR grid is observed in form of 0.2 Hz oscillation in the 765 kV Inter connecting link.

Oscillation in power System

OSCILLATION AND ITS CLASSIFICATION

- Small-Signal Stability is the ability of power system to maintain synchronism when subjected to small disturbances.
- Such disturbances occur continually on the system due to small variation in loads and generations.
- In today's practical systems, small signal stability is usually due to insufficient damping of one the systems mode.
- The small signal instability in power system can be either local or global in nature.
- The global problems are associated with inter-area oscillations. The global rotor angle stability problems are further classified as:
  1. A very low frequency oscillation mode involving all generators in the system: In such oscillation, system is essentially split into two parts and generators in one part swing against generator in other part. Frequency of oscillation is of the order 0.1-0.3 Hz.
  2. Higher Frequency modes involving sub-group of generators swinging against each other: Here frequency is in the typical range of 0.4-0.7 Hz.

  Ref : P. Kundur, Power System Stability and Control, (McGraw-Hill: New York, 1994).
- Spontaneous oscillations: Spontaneous oscillations arise in the power system when the damping of the mode has becomes negative with gradual change in power system conditions. Such oscillations grow and may reach a steady state in which the oscillations persist at constant magnitude.
- Oscillations due to a disturbance: Outage of a line or generator under unfavourable conditions (like faults) can result in oscillations by suddenly reducing damping of a mode. If the mode damping becomes negative, sustained or increasing oscillations result this may result in cascade tripping. If the mode becomes poorly damped, the disturbance can excite the mode to cause a transient oscillation in the grid. These transient oscillations eventually decay, but can be of sufficient amplitude and duration to be harmful.
- Forced oscillations: This is in general due to incomplete islanding or pulsating loads in power

  Ref : I.Dobson, F.L.Alvarado, C.L.DeMarco, P.Sauer, S.Greene, H.Engdahl, J.Zhang, "Avoiding and suppressing oscillations", final report for PSERC project. PSERC publication 00-01, December 1999, available from http://www.pserc.wisc.edu/

CASE STUDY

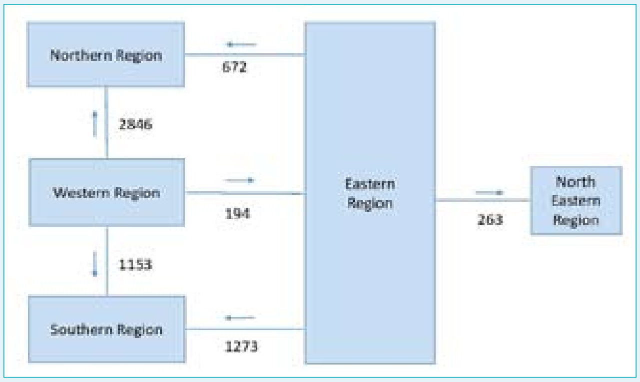
Spontaneous Oscillations on 28th January 2014 20:03:25 Hrs

ANTECEDENT CONDITIONS

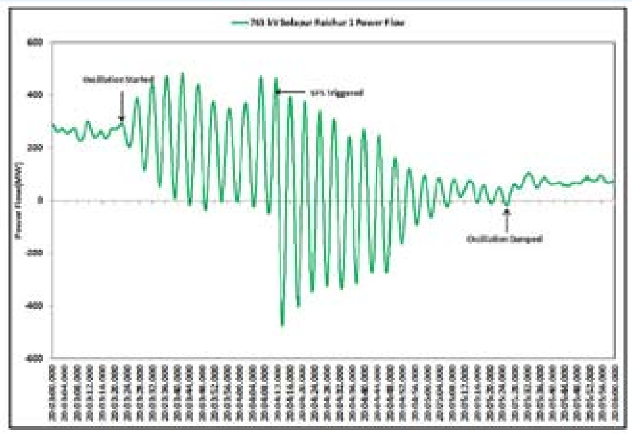
- NEWS grid frequency: 50.143 Hz

Region	Demand catered (MW)
WR	34816
NR	35728
ER	15785
SR	33159
NER	1601

- 765kV Solapur-Raichur ckt Power Flow : 264 MW (from Solapur to Raichur)

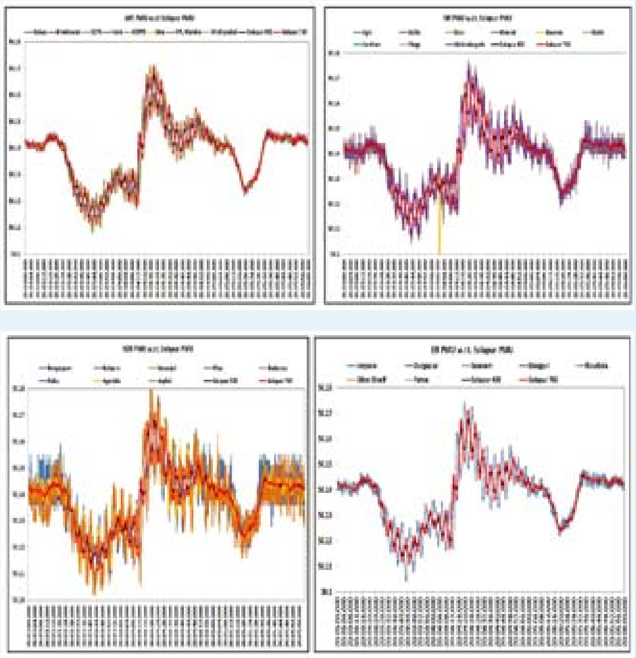


SPONTANEOUS OSCILLATIONS



- Oscillations starting time: 20:03:25.200 Hrs
- SPS signal time: 20:04:10.859 Hrs
- End time of oscillations: 20:05:24.800 Hrs
- Period of oscillation: 124 sec
- Largest swing in 765kV Solapur-Raichur Power flow: 936 MW

OSCILLATIONS IN FREQUENCY



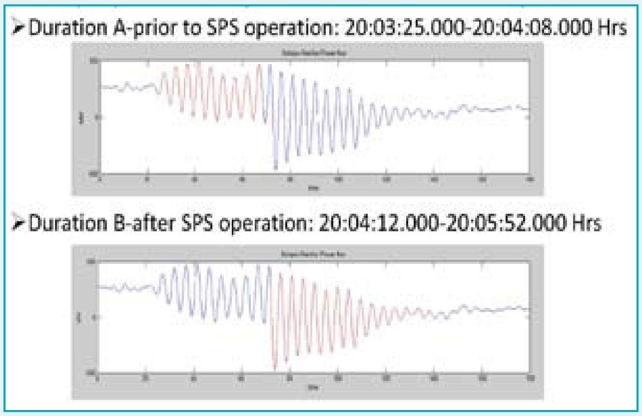
SPS OPERATION DURING THE OSCILLATION

- Signal received: S2_500
- Reason for SPS signa gneration low-" of 400MW/s limit on
- Effect:
  - InWR
    - KSK back down by 126 MW
    - JPLbackdownby25MW
  - InSR
    - load shedding by 423 MW

Oscillation got damped after the SPS Operation.

ANALYSIS OF THE SYNCHROPHASOR DATA

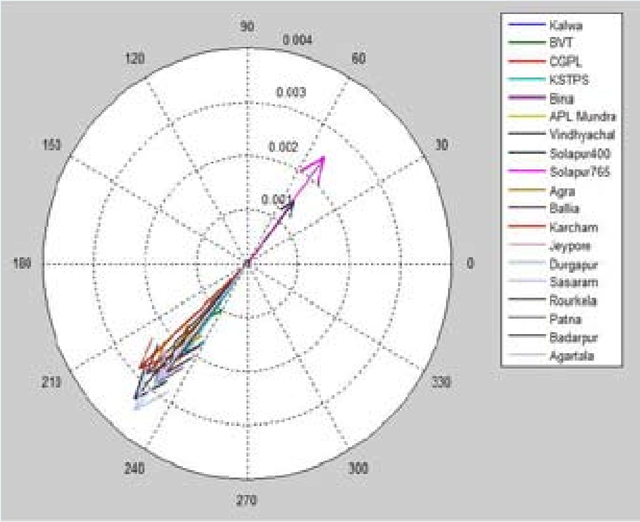
- For the purpose of analysis data divided into two parts:



SIGNAL: FREQUENCY DURATION: A

Mode 1: 0.235 Hz Damping: 0.0404

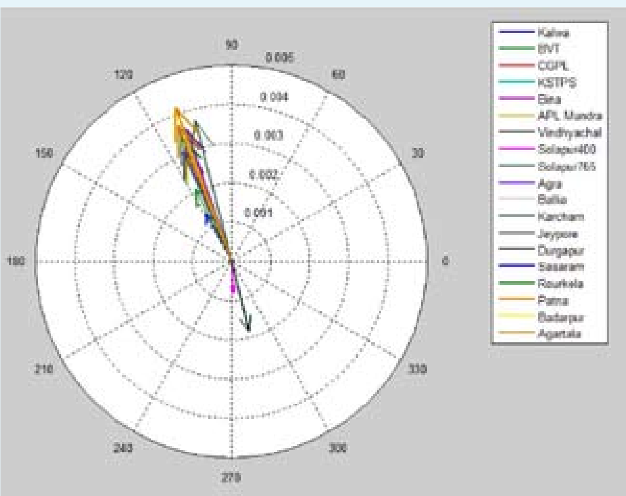
Maximum observability: NER region



Location of PMUs	Residues	Phase	Ratio wrt Agartala
Agartala	0.003513699	-128.9342	1.000
Badarpur	0.003347486	-131.3152	0.953
Patna	0.002883886	-128.7542	0.821
Karcham wangtoo	0.002877218	-137.5816	0.819
Ballia	0.002854867	-133.7308	0.812
Sasaram	0.002852821	-128.8934	0.812
Durgapur	0.002844862	-128.3679	0.810
Jeypore	0.002793353	-129.6198	0.795
Agra	0.002736694	-132.0607	0.779
Rourkela	0.00256035	-127.7510	0.729
Solapur 765	0.00250479	52.7205	0.713
Bina	0.002202337	-127.3406	0.627
Vindhyachal	0.002182826	-127.4042	0.621
Korba	0.002074708	-125.7671	0.590
APL mundra	0.002030105	-130.2839	0.578
CGPL	0.002014462	-129.2872	0.573
Solapur 400	0.001477003	51.7953	0.420
Bhadrawati	0.001221022	-125.9520	0.348
Kalwa	0.000543572	-134.8838	0.155

Mode 2: 0.1908 Hz Damping: 0.0074

Maximum observability: NER region

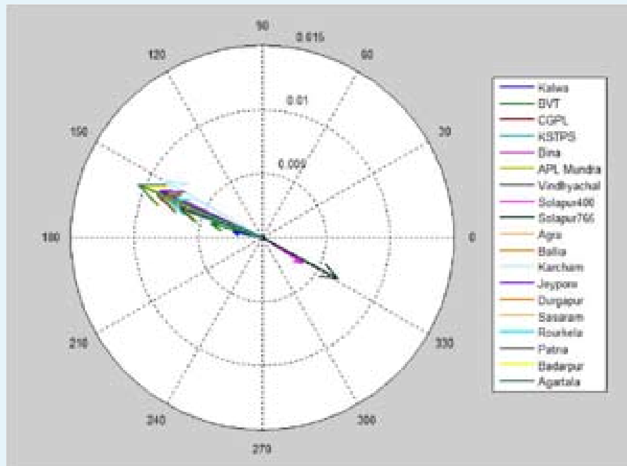


Location of PMUs	Residues	Phase	Ratio wrt Agartala
Agartala	0.004177	109.9922	1.000
Badarpur	0.004174	110.2371	0.999
Patna	0.00371	111.5053	0.888
Karcham Wangtoo	0.003688	104.5299	0.883
Ballia	0.003686	110.9249	0.882
Sasaram	0.003683	111.4572	0.882
Durgapur	0.003682	111.5414	0.881
Jeypore	0.003674	110.1213	0.879
Agra	0.003552	108.8109	0.850
Rourkela	0.003406	111.9684	0.815
Bina	0.00304	113.2484	0.728
Vindhyachal	0.003031	113.64	0.726
CGPL	0.002916	113.1741	0.698
Korba	0.002914	114.1803	0.698
APL Mundra	0.002875	113.658	0.688
Bhadrawati	0.002056	116.4959	0.492
Solapur 765	0.001819	-76.0392	0.435
Kalwa	0.001383	118.1173	0.331
Solapur 400	0.000803	-85.9537	0.192

SIGNAL: FREQUENCY DURATION: B

Mode 1: 0.205 Hz Damping: 0.0304

Maximum observability: NER region

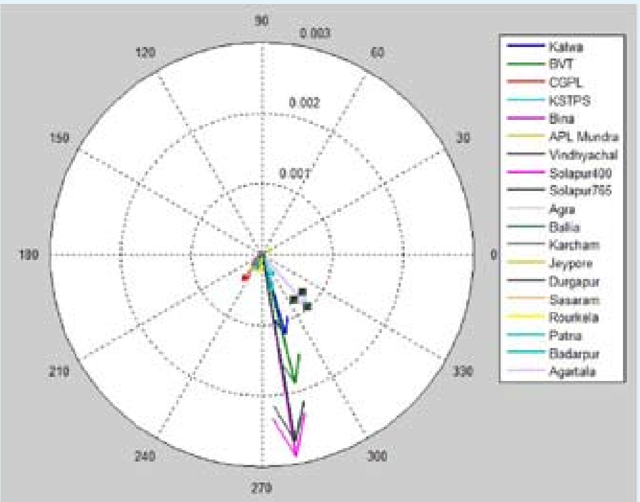


Location of PMUs	Residues	Phase	Ratio wrt Agartala
Agartala	0.01061	156.884	1.000
Badarpur	0.010401	157.3393	0.980
Ballia	0.008979	156.4343	0.846
Patna	0.008879	157.6266	0.837
Karcham Wangtoo	0.008857	149.7087	0.835
Sasaram	0.008822	157.6129	0.831
Jeypore	0.008764	155.3219	0.826
Durgapur	0.008749	157.8254	0.825
Agra	0.008487	154.8446	0.800
Rourkela	0.007927	158.234	0.747
Bina	0.006941	159.9881	0.654
Vindhyachal	0.006861	160.3688	0.647
CGPL	0.006744	159.7968	0.636
Solapur 765	0.006708	-28.2768	0.632
APL Mundra	0.006649	159.932	0.627
Korba	0.006486	161.135	0.611
Bhadrawati	0.004111	164.859	0.387
Solapur 400	0.003779	-31.9814	0.356
Kalwa	0.002353	168.6421	0.222

SIGNAL: R PHASE VOLTAGE DURATION: A

Mode 1: 0.2254 Hz Damping: 0.0353

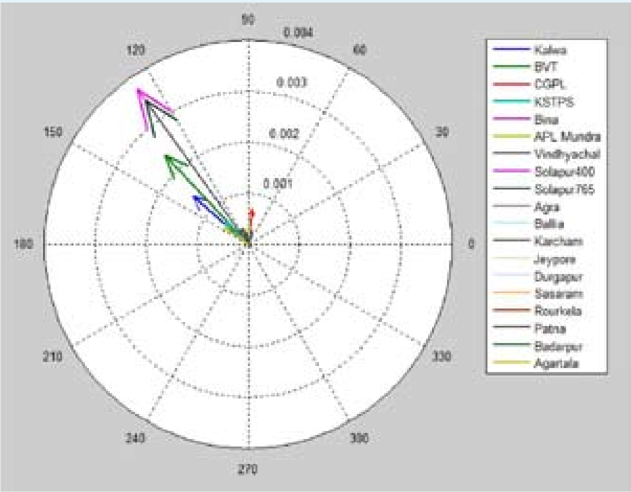
Maximum observability: Solapur, Bhadrawati, Kalwa



Location of PMUs	Residues	Phase	Ratio wrt Solapur 400
Solapur 400 Va	0.002897	-80.4414	1.000
Solapur 765 Va	0.002685	-79.7683	0.927
Bhadrawati Va	0.001875	-75.381	0.647
Kalwa Va	0.001171	-73.2834	0.404
Agartala Va	0.000979	-48.4496	0.338
Korba Va	0.000527	-74.0075	0.182
CGPL Va	0.000463	-126.503	0.160
Badarpur Va	0.000345	-61.4042	0.119
Rourkela Va	0.000262	-97.1732	0.091
APL Mundra Va	0.00026	-128.684	0.090
Sasaram Va	0.000237	-115.985	0.082
Vindhyachal Va	0.000221	-102.468	0.076
Patna Va	0.000211	-118.655	0.073
Bina Va	0.000208	-132.245	0.072
Ballia Va	0.000188	-121.768	0.065
Durgapur Va	0.000187	-100.098	0.065
Karcham Wangtoo Va	0.000169	-149.794	0.058
Jeypore Va	0.000162	27.83193	0.056
Agra Va	8.61E-05	-128.303	0.030

Mode 2: 0.1900 Hz Damping: 0.0405

Maximum observability: Solapur, Bhadrawati, Kalwa

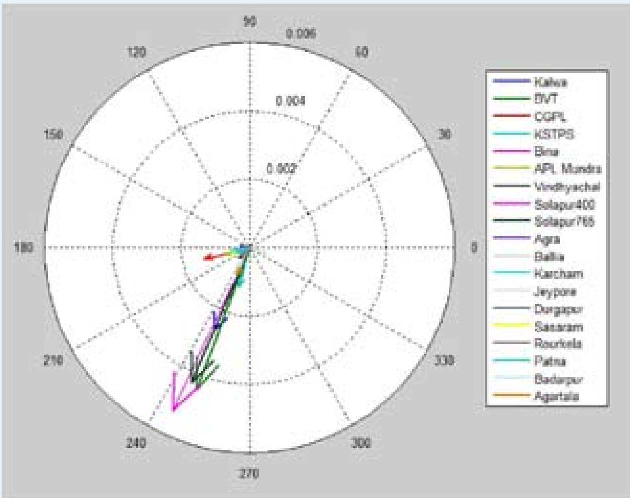


Location of PMUs	Residues	Phase	Ratio wrt Solapur 400kV
Solapur 400 Va	0.00374	125.5177	1.000
Solapur 765 Va	0.00346	125.4773	0.925
Bhadrawati Va	0.002395	132.8204	0.640
Kalwa Va	0.00145	138.8575	0.388
CGPL Va	0.000693	82.82403	0.185
Korba Va	0.000627	135.1247	0.168
Agartala Va	0.000552	142.782	0.148
Jeypore Va	0.000382	-133.972	0.102
APL Mundra Va	0.000373	85.6303	0.100
Badarpur Va	0.000336	119.4839	0.090
Vindhyachal Va	0.000323	108.4626	0.086
Bina Va	0.000313	83.09492	0.084
Sasaram Va	0.000303	98.61878	0.081
Ballia Va	0.000281	92.00105	0.075
Karcham Wangtoo Va	0.000277	70.86219	0.074
Rourkela Va	0.000264	123.0057	0.071
Patna Va	0.000245	98.18052	0.065
Durgapur Va	0.000209	123.8477	0.056
Agra Va	0.000154	83.98072	0.041

SIGNAL: R PHASE VOLTAGE DURATION: B

Mode 1: 0.2074 Hz Damping: 0.03764

Maximum observability: Solapur, Bhadrawati, Kalwa



Location of PMUs	Residues	Phase	Ratio wrt Solapur 400 kV
Solapur 400 Va	0.005283	-115.362	1.000
Bhadrawati Va	0.004437	-110.52	0.840
Solapur 765 Va	0.004303	-113.263	0.814
Kalwa Va	0.002657	-113.029	0.503
CGPL Va	0.001373	-166.455	0.260
Korba Va	0.001189	-105.419	0.225
Agartala Va	0.000868	-114.499	0.164
APL Mundra Va	0.000725	-163.909	0.137
Badarpur Va	0.000656	-122.018	0.124
Karcham Wangtoo Va	0.000547	-172.357	0.104
Sasaram Va	0.000537	-158.74	0.102
Jeypore Va	0.0005	-16.6661	0.095
Ballia va	0.000482	-158.706	0.091
Vindhyachal Va	0.000459	-137.395	0.087
Patna Va	0.000432	-160.913	0.082
Rourkela Va	0.00043	-119.624	0.081
Bina Va	0.000404	-171.606	0.076
Durgapur Va	0.00034	-131.798	0.064
Agra Va	0.000278	171.4192	0.053

SUMMARY OF ANALYSIS

Modal Resonance A Unique Phenomenon

Duration A (20:03:25.000 Hrs – 20:04:08.000 Hrs)					
Sr. No.	Signal	Mode 1		Mode 2	
		LFO (Hz)	Damping ratio	LFO (Hz)	Damping ratio
1	Frequency	0.235	0.0404	0.1908	0.0074
2	Vr	0.2254	0.0353	0.1900	0.0405
3	P	0.218	0.0578	0.1973	0.0649

Duration B (20:04:12.000 Hrs – 20:04:52.000 Hrs)			
Sr. No.	Signal	Mode	
		LFO (Hz)	Damping Ratio
1	Frequency	0.205	0.034
2	Vr	0.2074	0.03764
3	P	0.212	0.0506

WHAT IS MODAL RESONANCE ?

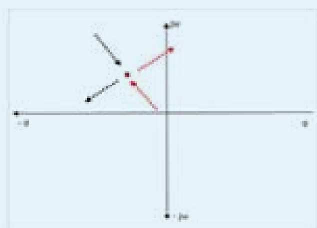


Fig : Modal interaction during ideal strong resonance

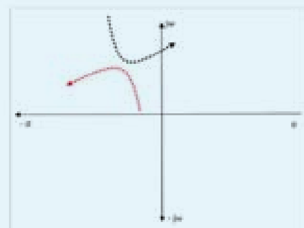


Fig : Modal interaction during in practically observed strong resonance in real power system.

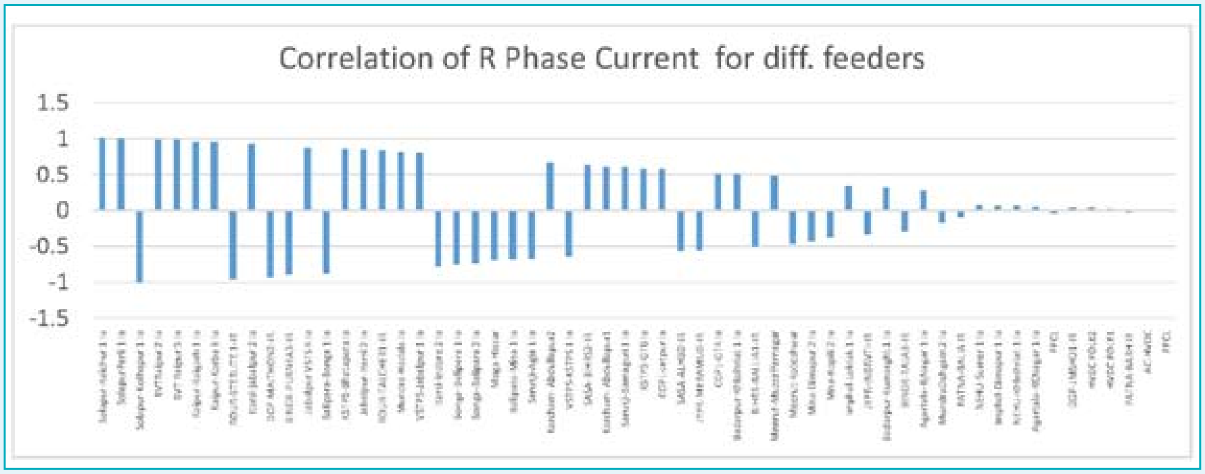
References

1. "Is strong modal resonance a precursor to power system oscillations?" I. Dobson, J. Zhang, S. Greene, H. Engdahl, P.W. Sauer IEEE Trans. Circuits and Systems, Part 1, vol. 48, no. 3, March 2001, pp. 340-349.
2. "Strong resonance effects in normal form analysis and subsynchronous resonance".I.Dobson , Bulk Power System Dynamics and Control V, August 26-31, 2001, Onomichi, Japan, pp. 563-574
3. "Modifying eigenvalue interactions near weak resonance", V. Auvray, I. Dobson, L. Wehenkel, IEEE International Symposium Circuits & Systems, Vancouver Canada, May 2004, vol. 5, pp 992-995.
4. "Perturbations of weakly resonant power system electromechanical modes", I. Dobson, E. Barocio, IEEE Trans. Power Systems, vol. 20, no. 1, Feb. 2005, pp. 330-337

MODE PROPAGATION PATH DETERMINATION

Using correlation to know how the mode have propagated in the grid.

Basically indicate through which path the mode has interacted and propagated.



MODE PROPAGATION PATH BASED ON CORRELATION

OBSERVATIONS

- Power flow variation on the link is bidirectional and is very sensitive to the changes occurring in either of the connected grid.
- Damping time 0.2 Hz observed is in range of 20 seconds to 51 seconds.
- Damping observed has been good except in one case of spontaneous oscillation.
- Mode propagation path is along the generator concentrated path. Need of PSS tuning of generators is important along the path.
- Need for Small signal model study for Indian Power system.
- Modal Resonance : Need of Further research in the area at the global level.

Today you Burn, Tomorrow Your Children will Feel the Heat