Central Electricity Regulatory Commission
New Delhi

GRID SECURITY
– NEED FOR TIGHTENING OF FREQUENCY BAND & OTHER MEASURES

CERC STAFF PAPER
March 2011

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1. Introduction

Power frequency reflects the load generation balance in the grid at a particular instant. Frequency is one of the most important parameters for assessment of the security of power system and the quality of power supply in any grid. It is to be maintained within the specified range in which all the electrical equipments are designed to perform safely and efficiently. Handling imbalances is an integral part of market design. In India, the balancing market is frequency dependent and market design must complement reliability. This discussion paper focuses on grid frequency and other issues related to grid security in India.

2. Power Supply Scenario in India

India is one of the largest synchronous interconnections in the world. The installed generation capacity as on 31st Jan 2011 is 170.23 GW. The revised target for generation capacity addition in 11th five year plan is 62 GW. The projected peak shortage and energy shortage in March 2012 is 6.5% and 2% respectively.

Table 1: Anticipated Power Supply Scenario in 2012

Period	Peak Demand (MW)	Peak Availability (MW)	Deficit (-) / Surplus (+) (MW)	Deficit (-) / Surplus (+) (%)
2011-12	152746	142765	-9981	-6.5
	Energy Requirement (MU)	**Energy Availability (MU)**	**Deficit (-) / Surplus (+) (MU)**	**Deficit (-) / Surplus (+) (%)**
2011-12	968659	948836	-19823	-2%
Demand as per 17th Electric Power Survey Source: Power Scenario at a Glance, January 2011, CEA				

3. Standards for Power Frequency in India

As per the Indian Electricity Rules 1956 (amended up to 25th Nov 2000), the permissible range for grid frequency was +/- 3 % of nominal i.e. 48.5 Hz to 51.5 Hz. The permissible frequency ranges (by manufacturers) for operation of various makes of steam turbine are shown in Figure 1. The nominal frequency of operation in Indian grid is 50.0 Hz and the permissible frequency band specified by Indian Electricity Grid Code (IEGC) is 49.5 Hz to 50.2 Hz w.e.f 3rd May 2010.

Table 2: Permissible range of operating frequency for steam turbines

S.NO.	TURBINE	FREQUENCY(HZ.)	TIME FOR OPERATION
1	100 MW,200 MW,210 MW of Russian Design	49.0 to 50.5	Continous unrestricted operation
		50.5 to 51.0	3 minutes at a stretch and 500 minutes in whole life
		48.0 to 49.0	3 minutes at a stretch and 500 minutes in whole life
		47.0 to 48.0	1 minute at a stretch and 180 minutes in whole life
		46.0 to 47.0	10 seconds at a stretch and 30 minutes in whole life
2	210 MW , 500 MW of KWU design	47.5 to 51.5	Continous unrestricted operation
		Below 47.5	2 hours in whole life
		Above 51.5	2 hours in whole life
3	200 MW of GE (ANSALDO) design	48.5 to 50.5	Continous unrestricted operation
		50.5 to 51.0	90 minutes in whole life
		48.0 to 48.5	90 minutes in whole life
		51.0 to 51.5	15 minutes in whole life
		47.5 to 48.0	15 minutes in whole life
		51.5 to 52.0	1 minute in whole life
		47.0 to 47.5	1 minute in whole life
4	RAPS/NAPS 2x220 MW English Electric	48.5-Operating Frequency	Summation in lifetime t<= 3 minutes where 't' is the operating time for incidents of frequency excursion below 48.5 Hz.
		>51.5	Not recommended
5	110 MW of Skoda Design	49.0 - 51.0	Continous unrestricted operation
		48.0 - 49.0	2 hours at a stretch and 30 hours in a year
		47.0 - 48.0	30 minutes at a stretch and 2 hours in a year

Source : Extracts from the report of "Task Force on Frequency Control" NREB,1992

4. **Initiatives taken by CERC for improving the frequency profile in the grid**

Sale-purchase of electric energy in India is at the rates agreed in the respective contracts. These contracts are scheduled in the grid by the appropriate load despatch centres as per the requests of the sellers/buyers. However during actual operation the quantum of injection into the grid by the seller and/or the off-take from the grid by the buyers may deviate from agreed schedule. The quantum of deviation from schedule is known as Unscheduled Interchange (UI) that is settled at the pre-defined Unscheduled Interchange rate (UI vector) specified by the commission. The UI rate at a certain time is dependent on the frequency at that time. Thus the UI vector is linked to the frequency. CERC has taken several measures to improve the frequency profile in the grid by gradually tightening the permissible operating band for frequency and the volume of unscheduled Interchange by the entities in the grid.

The normal operating frequency range allowed by the Indian Electricity Grid Code till 31st March 2009 was 49.0 to 50.5 Hz. The frequency band was tightened by CERC in subsequent amendments to IEGC. The frequency band w.e.f 3rd May 2010 is 49.5 Hz to 50.2 Hz.

Table 3: Operating range for frequency specified in IEGC

S No.	Period	Operating Range (in Hz)
1	Till 31st March 2009	49.0 to 50.5
2	1st April 2009 to 2nd May 2010	49.2 to 50.3
3	w.e.f 3rd May 2010	49.5 to 50.2

Similarly the UI mechanism has been revised several times in the past to improve the frequency profile in the grid. The various stages of evolution of the UI mechanism has been displayed as Annexure. The continuous improvement in the grid frequency profile is evident from the frequency profile recorded in the North-East-West grid in the past few years as displayed in figure 2 and 3 below.

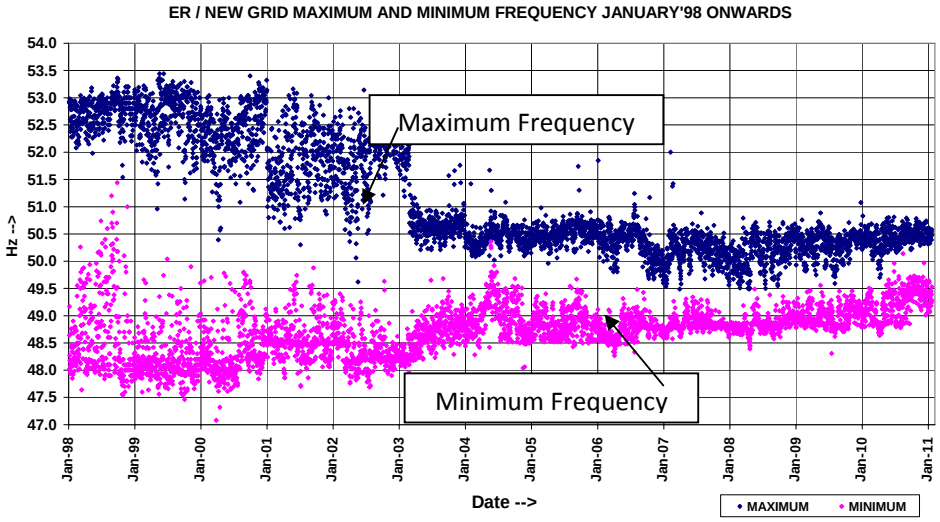

Figure 1: Maximum and minimum frequency recorded in NEW grid

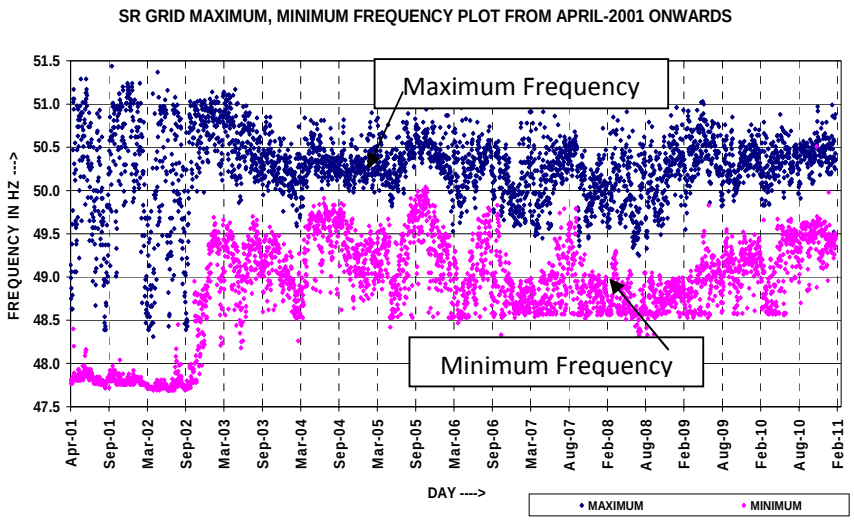

Figure 2: Maximum and Minimum frequency recorded in SR grid

5. **Significant developments and concerns in Indian grid in near future**

The power system in India is expanding at a fast pace to meet the requirements of Indian economy. Few significant developments in the power system that necessitate discussion on the frequency standards in the Indian grid have been highlighted below.

a) Growing size of Interconnection

Indian grid is presently demarcated into five regional grids. Four out of the five grids (except Southern Grid) are operating in synchronism since August 2006. There are plans to integrate the Southern Grid with the rest of the grid through synchronous ties in near future (presently it is through asynchronous HVDC link). Indian grid is also striving to expand by establishing interconnection with neighbouring countries. Bhutan is already synchronously interconnected while Nepal has several asynchronous ties with the Indian grid (AC radial links). A project for establishing asynchronous ties with Bangladesh through HVDC back-to-back link is already under progress. A

tighter operating band for frequency is essential for secure operation of a large synchronous interconnection.

b) Size of Generating Units and generation complex

Presently the size of the largest generating unit in India is 660 MW and very soon 800 MW unit (Mundra UMPP) and 1000 MW unit (Nuclear unit at Kudunkulam) are also expected to be synchronized.

Table 4: Population of different size of generators

S No.	Unit Size	Number of units
1	800 MW and >800 MW	Expected soon
2	660 MW	2
3	600 MW	4
4	540/500/490 MW	45
5	300/330/380 MW	13
6	250/210/200 MW	244
7	140/150/170/185 MW	74
8	100/110/120 MW	205
9	Less than 100 MW	983
10	**Total**	**1570**

Table 5: Number of large generation complex

S No.	Size of generation complex	Number
1	4000 MW and above	UMPPs expected soon
2	2000 MW to 4000 MW	7
3	1000 MW to 2000 MW	36
4	Below 1000 MW	325
5	**Total**	**368**

Table 6: Incidents of complete power station trip (May 2010 to Jan 2011)

S No.	Generation loss	Number of instances
1	> 2000 MW	Tripping of stations such as Korba and Vindhyachal before May 2010
2	1000 MW to 2000 MW	4
3	500 MW to 1000 MW	3

The system is generally planned for outage of single largest unit outage. However number of incidents where the complete power station has tripped is also significantly high. In fact almost all large power stations in the country have gone under forced outage at least once. The grid frequency needs to be maintained at level so that the system is able to bear the impact of such large but credible contingencies, even if it is with the help of suitable protection schemes such as load shedding schemes initiated by Under frequency, Rate of Change of frequency and Under Voltage. The setting of automatic load shedding through under frequency and rate of change of frequency relays is shown in Tables below.

Table 7: Under Frequency Relay settings adopted in India

Region	Stage-I	Stage-II	Stage-III
Northern Region	48.8 Hz	48.6 Hz	48.2 Hz
Western Region	48.8 Hz	48.6 Hz	48.2 Hz
Eastern Region	48.5 Hz	48.2 Hz	48.0 Hz
North-eastern region	48.8 Hz	48.5 Hz	48.2 Hz
Southern Region	48.8 Hz	48.5Hz	48.2 Hz

Table 8: Rate of Change of Frequency Relay setting adopted in Indian grid

Region	Stage-I	Stage-II	Stage-III
NR	0.1 Hz per sec and 49.9 Hz	0.2 Hz per sec and 49.9 Hz	0.2 Hz per sec and 49.9 Hz
WR	0.1 Hz per sec and 49.9 Hz	0.2 Hz per sec and 49.9 Hz	
SR	0.3 Hz per sec and 49.5 Hz (Alarm)	0.3 Hz per sec and 49.3 Hz (Trip)	

c) Growing expectations of consumers

A large interconnection caters to a diverse category of consumers. A narrow operating range for grid frequency significantly reduces wear and tear in electrical machines and thus increases their life. Moreover, with the increase in the proportion of sophisticated consumer loads such as process industries, traction locomotives and silicon loads the expectation of a better power quality from the grid is also rising.

d) Impact of frequency on voltage

It has been observed from studies that increase in frequency results in increase in voltage and decrease in frequency results in decrease in voltage. In Northern grid it has been observed that one Hz frequency increase/decrease is equivalent to 8 kV increase or decrease in voltage. This would have a significant impact on transmission losses and efficiency in the grid.

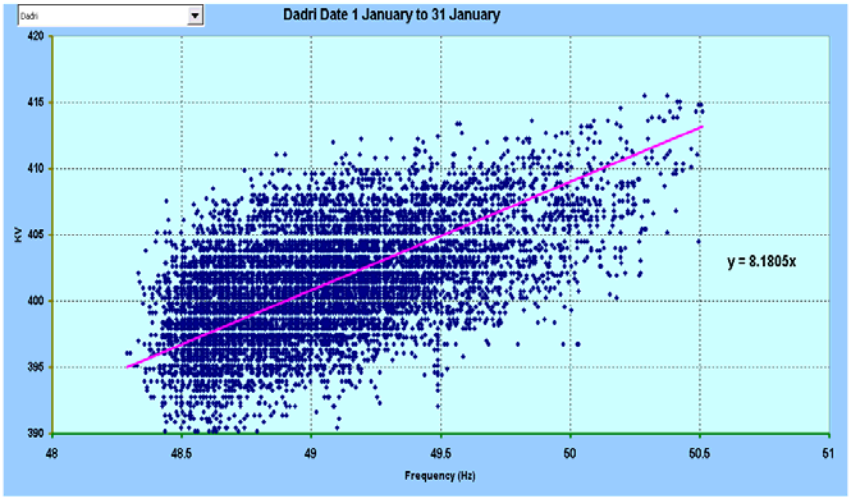

Figure 3: Impact of grid frequency on grid voltage

a) Frequency fluctuations and primary response from generators

It has been observed that the power number in NEW grid and SR grid is 1800 MW per Hertz and 1020 MW per Hertz respectively. Tightening of frequency band by 0.1 Hz may imply reduction in demand met by approximately 180 MW in NEW Grid and approximately 102 MW in SR Grid. However, grid operation within a narrow range would encourage utilities to provide primary response from their generators. This would help in arresting the wide variations in frequency and network loadings during sudden change in injection/withdrawal from the grid. Thus improved security and efficiency gains obtained through tightening of frequency band are much larger.

b) Volume of unscheduled Interchange

A frequency dependent unscheduled interchange mechanism is in place in the Indian grid. A wide operating range of frequency creates room for large volume of unscheduled interchanges. The volume of UI and the Scheduled Interchanges is shown in figure below.

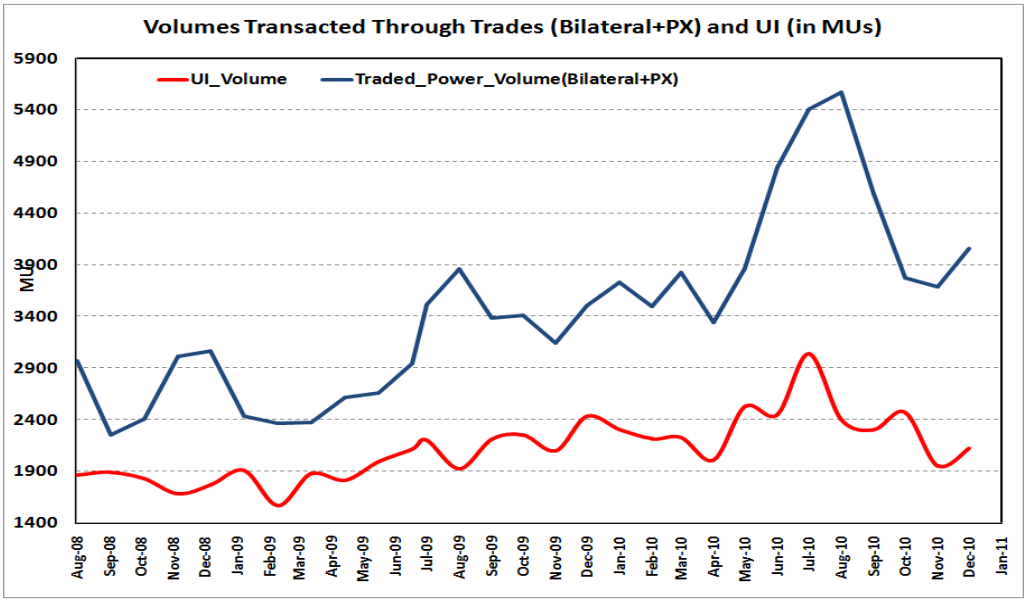

Figure 4: Volume of Scheduled interchange and Unscheduled Interchange

Several market players participate in the Indian market with a highly unbalanced portfolio. The unpredictability in the behaviour of such market players has serious implications for grid security. Therefore CERC has taken several initiatives to encourage market players to shift from Unscheduled Interchange to Scheduled Interchange.

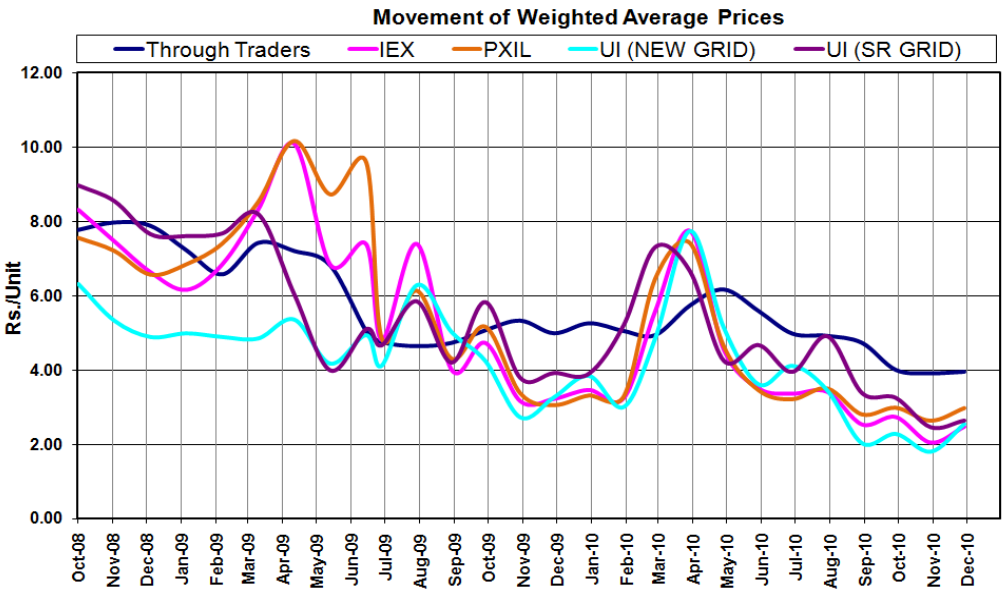

Figure 5: Trend of weighted Average Prices

A comparison of UI rate with the weighted average energy price in the bilateral and collective transactions in the NEW grid reveals that the UI rate has been lower than the negotiated price in bilateral transactions and the discovered price in the Power Exchange. This is a positive development and implies that buyers are willing to pay a premium for scheduled interchange that provides higher certainty. Therefore it is desirable to encourage the reliance on scheduled interchange through the available price signals and by enforcement of the UI volumes cap as mandated in the CERC regulations on Unscheduled Interchanges. The SERCs could also consider similar measures.

c) Integration of renewable energy

Integration of renewable energy in the grid is one of the biggest thrust areas. The contribution from wind energy is highest in the renewable portfolio. The installed wind generation capacity as on 30th Sep 2010 is 6070 MW. This is expected to be 13065 MW by Dec 2012. Considering the high

variability and unpredictability of generation from renewable, the injection from wind energy can be safely absorbed in the grid only if the frequency in the grid is maintained in a comfortable range.

d) Simulation and modelling

The focus in power system and electricity market operation planning is gradually shifting from empirical studies to quantitative analysis using simulations studies. The software used in modelling generally assumes a stable frequency. A stable frequency regime would facilitate comparison of simulated and actual system behaviour.

2. Comparison of permissible frequency in other countries and views in India

It is evident from the previous sections that the wide range of permissible frequency by design has economic as well as security concerns in a large grid. In this context it the permissible deviation from the nominal frequency prevailing in other countries has been examined and is shown is Table below.

Table 9: Permissible Frequency band in other countries

Country/Interconnection	Nominal frequency (Hz)	Permissible Frequency Band (Hz)	Permissible Deviation (%)
Eastern Interconnection (US)	60	59.95 - 60.05	+/-0.083%
Nordic countries	50	49.9 - 50.1	+/- 0.2%
Western Interconnection (US)	60	59.856 to 60.144	+/-0.24 %
Europe	50	49.8 - 50.2	+/- 0.4 %
India	50	49.5 – 50.2	- 1 % / +0.4 %
Other SAARC countries	50	49.5 - 50.5	+/- 1%

The intent of CERC on the desirable frequency band as mentioned in CERC order on ABT dated 4th January 2000.

Quote

"5.9.8 Another point for consideration is whether charges for overdrawal should be the same at 49.0 Hz and even below 49.0 Hz. It should be noted that the declared frequency in India is 50 Hz. An integrated power system should operate with a grid frequency hovering around 50 Hz. In practice however, the frequency range in India has been 48.5 Hz to 50.00 Hz. This is not desirable for achieving interconnected/integrated operation of the grid. With the additions to generation capacities, it is hoped that there may not be a drop below 49 Hz. ……. In fact the attempt should be to further narrow down the range with more generating capacities coming up and redundancy created."

Unquote

The issue also finds a mention in the Minutes of Meeting of 4th Coordination Forum held on 17th August 2009

Quote

"…It was highlighted in the presentation that low frequency situations are also resulting in sub-standard grid voltages. After the discussion, it was generally felt that there was a need to further narrow down the permissible frequency range from 49.5 Hz to 50.3 Hz w.e.f. January 2010 and from 49.8 Hz to 50.2 Hz w.e.f. January 2011…."

Unquote

3. Issues for discussion with respect to tightening of frequency band

The issues that need to be discussed are as below:

a) Tightening of operating frequency band is desirable

- What should be next operating range for frequency?

  Presently the operating range is 49.5 to 50.2 Hz

Suggested solution by CERC staff

In year 2011 : 49.7 to 50.2 Hz with a Step Size of 0.01 Hz

In year 2012 : 49.8 to 50.1 Hz with a Step Size of 0.01 Hz

- Deviations from schedule are inevitable and the deviations from schedule would be settled at the UI rate. What should be the permissible volume of Unscheduled Interchange for a control area as a percentage of its schedule?

  No change proposed.

4. Other issues related to grid security

Power System visualization and situational awareness are vital for decision making at the control centre. This requires reliable and fast communication between the generating stations/substations and the control centre. With the rapid expansion in the power system infrastructure in India a robust communication infrastructure is also required for power system operation and control. The major issue in this regard is the urgent need for an exclusive Regulation on communication system for Power Sector

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References

a. *CEA, '17th Electric Power Survey'*

b. *CEA, 'Power Scenario at a Glance', January 2011*

c. *Indian Electricity Rules 1956, as amended upto 25th November 2000*

d. *CERC, Indian Electricity Grid Code Regulation 2010, April 2010*

e. *CERC, Unscheduled Interchange charges and Related Matters regulations, 2010*

f. *NREB, 'Report of the Task Force on Frequency Control', December 1992*

g. *Dwarka Nath, 'Under frequency Trend relay as Power System Saviour', International Seminar on Grid Stability and Load Management, Nagpur, January 1996*

h. *NRPC, 'Report of the Sub-group constituted by Northern Region Operation Coordination Sub-committee to review Under Frequency Scheme in Northern Region', January 2005*

i. *CERC, Annual Report of the Market Monitoring Cell of CERC, 2009*

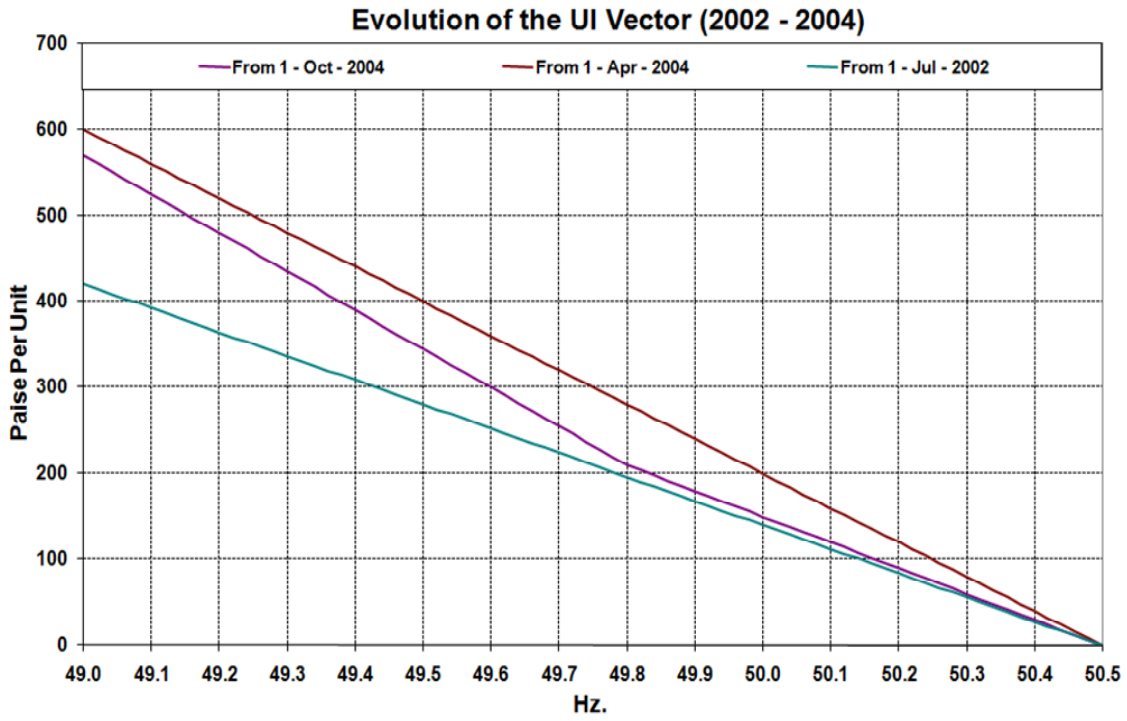
j. *S.K. Soonee et al., 'Frequency Response Characteristics of an Interconnected Power System-A Case Study of Regional Grids in India, 6th International R & D Conference on Sustainable Development of Water and Energy Resources, February 2007*

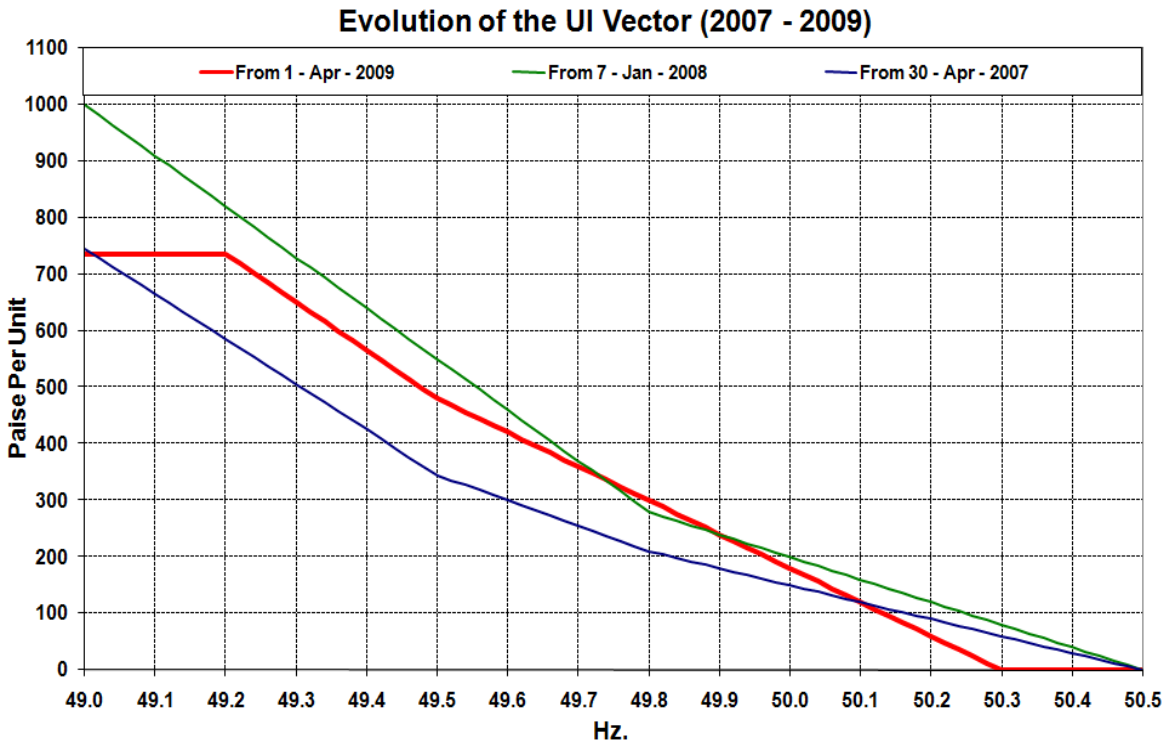
k. *S.K. Soonee et al., 'Reactive Power and System frequency Relationship a Case Study', 7th International R & D Conference, February 2009*

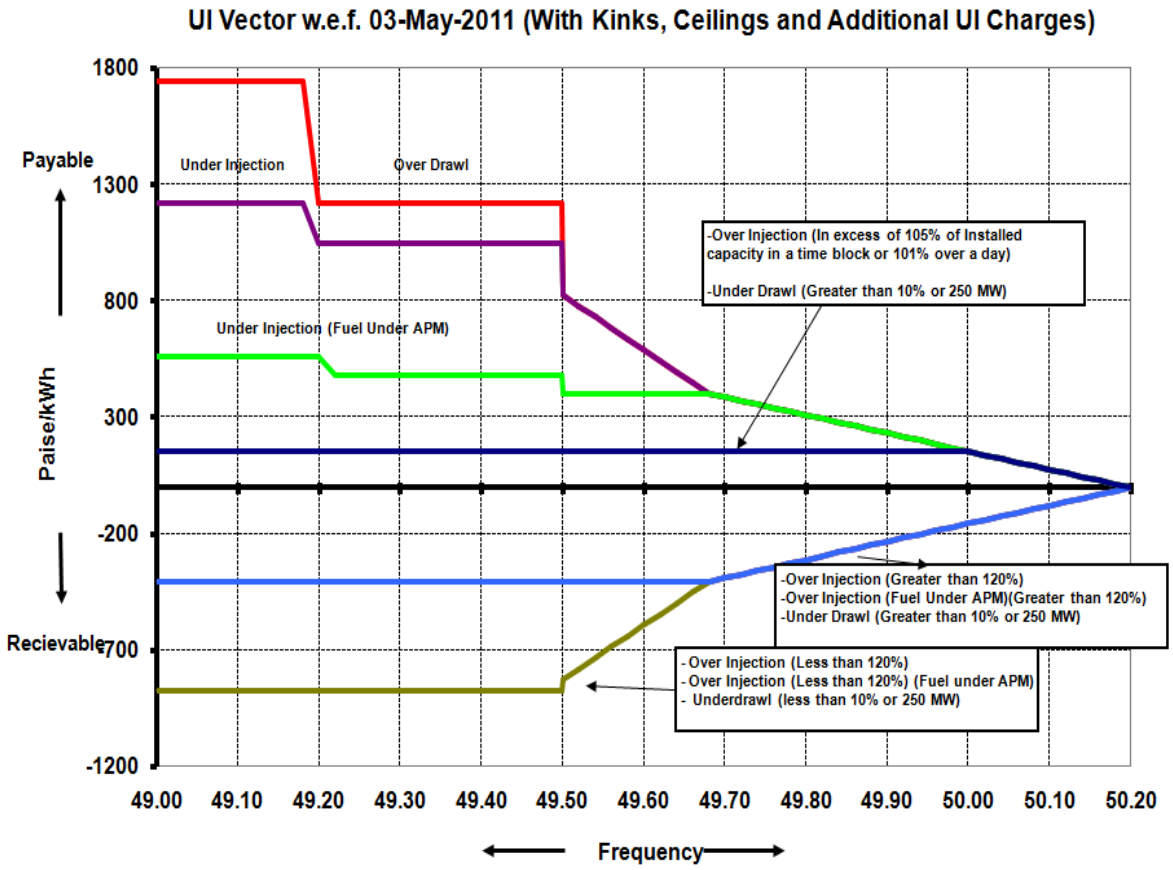
l. *CERC order on ABT, January 2000*

m. *Minutes of 4th Coordination Committee Meeting, August 2009*

Annexure


Evolution of the UI Vector (2002 - 2004)
From 1 - Oct - 2004
From 1 - Apr - 2004
From 1 - Jul - 2002
Paise Per Unit
700
600
500
400
300
200
100
0
49.0
49.1
49.2
49.3
49.4
49.5
49.6
49.7
49.8
49.9
50.0
50.1
50.2
50.3
50.4
50.5
Hz.


Evolution of the UI Vector (2007 - 2009)
From 1 - Apr - 2009
From 7 - Jan - 2008
From 30 - Apr - 2007
Paise Per Unit
1100
1000
900
800
700
600
500
400
300
200
100
0
49.0
49.1
49.2
49.3
49.4
49.5
49.6
49.7
49.8
49.9
50.0
50.1
50.2
50.3
50.4
50.5
Hz.


UI Vector w.e.f. 03-May-2011 (With Kinks, Ceilings and Additional UI Charges)
1800
1300
800
300
-200
-700
-1200
Payable
Recievable
Paise/kWh
Under Injection
Over Drawl
Under Injection (Fuel Under APM)
-Over Injection (In excess of 105% of Installed capacity in a time block or 101% over a day)
-Under Drawl (Greater than 10% or 250 MW)
-Over Injection (Greater than 120%)
-Over Injection (Fuel Under APM)(Greater than 120%)
-Under Drawl (Greater than 10% or 250 MW)
- Over Injection (Less than 120%)
- Over Injection (Less than 120%) (Fuel under APM)
- Underdrawl (less than 10% or 250 MW)
49.00
49.10
49.20
49.30
49.40
49.50
49.60
49.70
49.80
49.90
50.00
50.10
50.20
Frequency