CENTRAL ELECTRICITY REGULATORY COMMISSION
NEW DELHI

Coram:
Shri Gireesh B. Pradhan, Chairperson
Shri A.K.Singhal, Member
Shri A.S.Bakshi, Member
Dr. M.K.Iyer, Member

Date of Hearing: 28.4.2016
Date of Order : 14.6.2016

Petition No. 9/SM/2014

In the matter of

Investigation of tower collapse and load crash in Northern Region on 30.5.2014.

And
In the matter of

1. Power Grid Corporation of India Limited, "Saudamani",
Plot No.2, Sector-29,
Near IFFCO Chowk,
Gurgaon -122001 (Haryana)

2. Power System Operation Corporation Limited (POSOCO),
B-9, 1st Floor, Qutub Institutional Area,
Katwaria Sarai,
New Delhi 110 016 …Respondents

Petition No. 10/SM/2015

Investigation of Line Outage due to Tower Collapse in Northern Region on during April 2015 to June 2015 (1st Qtr. of 2015-16).

And
In the matter of

1. Power Grid Corporation of India Limited, "Saudamani",
Plot No.2, Sector-29,
Near IFFCO Chowk,
Gurgaon -122001 (Haryana)

2. Power System Operation Corporation Limited (POSOCO),
B-9, 1st Floor, Qutub Institutional Area,
Katwaria Sarai,
New Delhi 110 016

3. Central Electricity Authority
Sewa Bhawan R.K. Puram,
New Delhi-110066. ... **Respondents**

The Following were present:

Shri Vivek Sundariyal, Powergrid
Ms. Abiha Zaidi, POSOCO
Shri N. Nallarasan, POSOCO
Shri Rajiv Porwal, POSOCO
Ms. Jayantika Singh, POSOCO
Shri Shashi Bhushan, Powergrid
Shri R.P.S. Rana, Powergrid
Shri Gopal Ji, Powergrid
Shri J. Mazumder, Powergrid
Ms. Supriya Singh, NRLDC
Ms. Pragya Singh, NRLDC
Shri A.K. Vyas, Powergrid
Shri R.K. Singh, Powergrid
Shri Rajeev Kumar, Powergrid
Shri S.K.Ray Mohapatra, CEA

ORDER

Based on the information available from the website of Central Electricity Authority, the Commission vide order dated 19.6.2014 directed Power Grid Corporation of India Limited (PGCIL) to investigate into the incidences of collapse of transmission towers and tripping of transmission lines on 30.5.2014 and submit a report. Power System Operation Corporation Limited (NLDC) was directed to file the impact of collapse of the transmission towers on the system operation and grid security, the

action taken by concerned RLDC in this regard and the response of constituent entities to the direction of RLDC. Relevant portion of the said order is extracted as under:

> "1. As per information available on the website of Central Electricity Authority, on 30.5.2014 at 16.00 hrs to 19.00 hrs, Northern Region grid experienced heavy demand crash due to rain, dust storm/thunder storm, mainly in the States of Uttar Pradesh, Haryana, Uttarakhand and Delhi. The demand started reducing at 16.40 hrs and was minimal at around 17.15 hrs. The huge demand reduction resulted in a widespread high voltage throughout the system. The system frequency touched a high of 50.65 Hz at 17.05 hrs. It was also noted that Northern Region demand started declining steadily at a rate of approximately 200 MW/min and reached to 32780 MW at 17.15 hrs, around 8000 MW less than the demand at corresponding time of preceding day, and the power resulted in high frequency and high voltage in the system.
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> 2. It has been noticed that during this period, 68 AC transmission lines along with one HVDC Bi-pole line tripped which led to load crash of about 8000 MW in Northern Region including 3500 MW in Delhi. As per weather forecast of Indian Metrological Department and NOWCAST, all constituents of NR were alerted about the likelihood of the storm. As per the load crash report, the storm caused damage to many towers including 2 towers of 765 kV and one of 400 kV lines and 10 towers on various 220 kV transmission lines in Delhi. Collapse of transmission towers and lines tripping of such a large magnitude is alarming and needs to be investigated in detail.
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> 3. We direct Power Grid Corporation of India Limited to investigate into the incidences of collapse of transmission towers and tripping of transmission lines on 30.5.2014 and submit a report within two weeks from the date of issue of this order. The report shall also include the following:
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> (a) Failure of towers in different lines due to storm on 30.5.2014 in different regions in the country; and
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> (b) The wind speed which caused damage to towers, wind level for which the towers have been designed and IS design standard under which these tower were designed, year of commissioning of towers, updation on the maintenance activity, checks on strength of towers last done, etc."

2. As per the Commission`s direction, Power Grid Corporation of India Limited and Power System Operation Corporation Limited have submitted their reports.

3. Power Grid Corporation of India Limited (PGCIL), vide its affidavit dated 1.7.2014, has submitted its report on tower failure on the transmission lines in Northern Region on the two counts as under:

(a) **Details of tower failures**:

Name of the line/year of commissioning	**Extent of damage**	**Date of Restoration**
765 kV S/C Bhiwani-Jhatikaran, 2012	One tower at Loc. No. 174 damaged.	8.6.2014
765 kV Bhiwani-Meerut, 2014	One tower at Loc. No. 210 damaged. 4 adjacent towers partially damaged	15.6.2014
400 kV D/C Abdullapur-Deepalpur- Bawana, 2000	One tower at Loc. No. 418 collapsed. 2 adjacent towers partially damaged	11.6.2014

PGCIL has submitted that the cyclonic storm caused large scale damages in and around Delhi. Total 12 nos. of tower collapsed in three (3) transmission lines of DTL. A Large number of big trees uprooted and fallen on the road/ vehicle and there was massive disruption of air traffic at IGI airport.

(b) **Wind which caused damage to towers:**

(i) The overhead transmission lines are subjected to various loads during their life span. For design purposes, all loads can be estimated reliably except for the climatic loads (predominant being wind & ice load), which are dependent on correctness of the meteorological inputs. In Northern Region, the transmission towers are designed as per IS 802-1995, considering wind zone 4 under IS: 875 (part-3)-1987 with wind speed 47m/s and takes into account the recorded cyclones to some extent but do not account for other localized high intensity wind

conditions having narrow front viz. tornadoes, hurricanes, localized thunderstorms/dust storms, etc.

(ii) There are 7 lines of 765 kV, 4 of 500 kV HVDC and around 300 nos. circuits of 400 kV and below configurations operating in NR. On 30.5.2014, 3 towers had collapsed due to very high speed localized cyclone near the site of tower collapse. Therefore, the failures in these lines should be considered as isolated event occurred in extremely high localized wind conditions. On 30.5.2014, Indian Metrological Department (IMD) measured wind speed at Delhi as 92 kmph whereas the IGI airport reported a wind speed of 115 kmph during the storm which resulted in a massive disruption of air traffic. However, these measuring points are far away from the damaged tower locations.

(iii) IMD termed the storm as cumulonimbus which is a dense towering vertical cloud associated with thunderstorms and atmospheric instability, forming from water vapor carried by powerful upward air currents. Cumulonimbus can form alone, in clusters, or along cold frontsquall lines. Cumulonimbus progress from overdeveloped cumulus congestus clouds and may further develop as part of a supercell. A supercell is a thunderstorm that is characterized by the presence of a mesocyclone; a deep, persistently rotating updraft. For this reason, these storms are sometimes referred to as rotating thunderstorms. Since no installation for measurement of wind speed is available to capture entire area/ topography of entire length of the line, it would be difficult to assess the actual wind speed at locations where towers were affected.

(c) **Analysis of tower failure on PGCIL's lines:**

(i) The suspension 'A' type tower has also been designed for Narrow wind front condition in 765 kV transmission lines. 765 kV Bhiwani- Jhatikaran transmission line, tower had failed at location No 174 (A+0) due to heavy wind storm. 5 towers were failed in 765 kV Bhiwani–Meerut transmission line due to heavy wind storm. The failure started at location No. 210 and other failure at adjoining locations is subsequent damage due to impact of this tower.

(ii) The 400 kV D/C Abdullapur-Deepalpur-Bawana transmission line was designed with wind zone-4 in 2000. Subsequently, incidents of tower collapse occurred involving suspension towers having +18 M and +25 M extensions. After scrutiny, strengthening of +6M, +9M, +18M and +25M extensions was carried out in 2004 considering narrow front wind conditions. Since then no failures were reported in this line for last 10 years except the present instance. Localized cyclone/ whirl wind would have resulted in excessive load on DA+ 18 tower at location no 418 causing the failure. Other two towers appear to be secondary failure due to impact of loading caused by failure of tower at location no 418.

4. POSOCO, vide its affidavit dated 1.7.2014, has submitted its report on the impact of collapse of transmission towers and lines tripping on the system operation and grid security as under:

(a) 77 transmission lines were tripped during the storm period, out of which the tower collapse had been reported in 18 lines. All RLDCs were informed by NLDC about IMD forecast for the day by 16:20 Hrs. Backing down of the order of

2700 MW of generation was achieved in NR during the storm. Backing down of hydro was done throughout the country. There was a lesser demand of the order of 8000 MW w.r.t. previous day. The frequency rose to 50.65 at 17.05 hrs.

(b) HVDC Mundra-Mahendragarh tripped on Sub Synchronous Resonance (SSR) and further investigation needs to be done for ascertaining the cause and avoiding such tripping. Number of lines were tripped and grid became substantially weak due to thunderstorm and rainy weather conditions. During incidents, fault clearance time upto 1200 ms was observed which was much more than the CEA standards.

(c) After consistent follow up of NRLDC, generation backing down by respective State control area was carried out.

(d) The scope of improvement in which it has suggested that need for quick backing down of generation in respective State control area, bringing in more flexibility for generation reduction, part load generation, two shifting operation, etc. Better O&M practices for transmission lines should be adopted and various aspects of design margins and design considerations for wind speed of towers should be considered.

5. PGCIL under its letter dated 13.10.2015 has submitted that tower failure report was deliberated in the meeting of Standing Committee of Experts constituted to investigate failure of towers and suggest remedial actions to avert reoccurrence of such

failure in future. PGCIL has placed on record final report/recommendations of CEA. CEA in its report dated 19.1.2015 has submitted that the meeting of Standing Committee of Experts to carry out investigation of failure of transmission line towers of power utilities was held on 19.6.2014 and 12.9.2014 to discuss the causes of failure of the transmission line during the period from April, 2014 to July, 2014. The Committee observed that the following towers of 765 kV, 400 kV and 220 kV transmission lines were failed during the period from April, 2014 to July, 2014:

Transmission Lines	Date of Collapse	No of towers failed
765 kV S/C Meerut-Bhiwani Line	30.5.2014	5
765 kV S/C Bhiwani-Jhatikalan	30.5.2014	1
765 kV S/C Gaya-Fatehpur Line	31.5.2014	15
400 kV D/C Abdullapur-Bawana Line	30.5.2014	3
LILO of one circuit of 220kV D/C Tanakpur-Bareilly line at Sitarganj	23.5.2014	2
400kV D/C Maithon- Mejia line	11.6.2014	3
400 kV D/C Kaithal-Patiala line	13.6.2014	8
400 kV D/C Bhiwani-Jind line	29.6.2014	5
400 kV D/C Korba-Raipur line	29.6.2014	3
765 kV S/C Bina-Indore line	12.7.2014	1

6. PGCIL has submitted that the Committee has classified the pattern of failure of towers of lines of various voltage levels as under:

(i) Towers have buckled from stub level leading to complete collapse of towers with/without damage to tower foundation.

(ii) Towers have buckled from the top of 1stpanel(normal tower) level with/without damage to tower foundation.

(iii) Towers have buckled from bottom cross arm level or top cross arm or peak broken without any damage to lower portion of the tower and foundation.

(iv) Towers were failed due to sabotage/theft of tower members.

(v) Towers were failed due to falling of tree on the line during high intensity storm.

7. The Standing Committee has made the following recommendations to PGCIL:

(i) The design of towers should be reviewed for further strengthening, even though the transmission lines were designed according to IS:802(1995), in case of more failure occurs in future in such lines.

(b) The patrolling of line needs to be increased in theft prone areas in order to avoid failure due to theft of tower members. The local people should be educated by PGCIL and involved for safety of the towers.

(c) Coping of Chimneys, wherever required, needs to be done to avoid accumulation of water near stubs.

8. During the course of hearing on 14.10.2014, the representative of CEA submitted that prior to 1997, transmission towers were designed considering three wind zones. However, in 1997, country was demarcated into six wind zones and now towers are accordingly designed considering a reliability factor of '2' for 765 kV and '1' for 400 kV lines. The representative of CEA further submitted that the tower damage in 765 kV Gaya-Fatehpur line was also discussed in Standing Committee meeting held on 19.6.2014. CEA, vide ROP for the hearing 14.10.2014, was directed to investigate the issue in detail and submit a report in this regard. PGCIL, vide Record of Proceedings for the hearing dated 14.10.2014, was directed to investigate in coordination with CEA

in detail failure of towers on 30.5.2014 and 31.5.2014 considering the structural, and workmanship aspects, material used and O&M practices involving academia and submit a report and suggest remedial measures. POSOCO was directed to investigate the incident of SSR, delayed generators response and delayed clearance of faults on the transmission system in consultation with CEA and submit a report in this regard.

9. CEA, vide its letter dated 25.1.2016, has submitted report on failure of tower as on 31.5.2014 including failure of towers of 765 kV Gaya- Fatehpur S/C transmission line on 31.5.2014. The report has been summarized as under:

(a) 765 kV AC transmission network forms the top layer high capacity/bulk power transmission corridor of Indian transmission system. The 765 kV AC transmission system offers higher power transmission capacity per unit (or meter) of Right of Way (RoW) and lower transmission losses at reduced environmental impact. In India, the first 765 kV AC transmission line (409 km), between Anpara and Unnao, was commissioned in 1990s as Single Circuit (S/C) line and was charged initially at 400 kV. Towers were designed according to old Indian Standards (1977) with three wind zones [low, medium and high wind zones] based on concept of factor of safety. Sipat-Seoni 765 kV S/C line (336 km) and associated sub-stations, commissioned in the year 2007, became the first 765 kV transmission system which connected the 765 kV generating station at Sipat (NTPC) with 765 kV sub-station at Sioni (PGCIL). The maximum power transfer in a 765 kV S/C line is generally expected to be about 2200- 2300 MW. During initial phase of construction of 765 kV

S/C lines, the towers with horizontal configuration were introduced with Right of Way (RoW) of 85 m.

(b) Since, in plain terrains, percentage of tangent/suspension towers are normally more compared to tension/angle towers, there is tendency to optimize the design (without much safety margin in design) in order to economize the cost of transmission lines. Over the years, it was observed that most of the failed towers of transmission lines are of suspension type. Therefore, wind zones were reviewed. At present, six wind zones are being considered for design of towers based on the modified wind map of the country. However, the wind speed mapping for the entire country is under further revision by Bureau of Indian Standards based on inputs from Structural Engineering Research Centre (SERC), Chennai due to change in wind speed pattern in certain part of the country. The working load design concept i.e. concept of factor of safety has been changed to ultimate load concept. Presently, the philosophy of design is based on the probabilistic concept and the reliability level is being considered based on voltage level, tower, conductor configuration and special application. Since, the new design philosophy was adopted in the year 1995, the Indian Standard was modified without taking into consideration narrow front wind on tower body and 75% of wind in broken wire condition for design of suspension towers. However, as per decision in CBI&P forum, the suspension towers of transmission lines are being designed for narrow front wind on tower body and 75% of wind in broken wire condition considering the rate of failure of suspension towers. In the process, the failure rate of suspension

towers has come down. The Indian Standard is under revision to incorporate such provision.

(c) During 2005, the tower configuration for 765 kV S/C transmission lines was modified to delta configuration with prime objective to reduce RoW. In the process, RoW requirement was reduced from 85m to 64m. According to PGCIL, the first 765 kV suspension tower (tower Type-A) with delta configuration had failed during proto testing at M/s RPG test station, Jabalpur. However, after strengthening of some of the members, the tower was retested and the tower had successfully passed the tests.

(d) Gaya-Fatehpur 765 kV S/C transmission line (345 km) constructed by KPTL was designed with delta configuration as per IS 802 (1995) with Wind Zone-4 and reliability level 2 taking into consideration narrow front wind on tower body and 75% of wind in broken wire condition for design of suspension towers as per decision in CBI&P forum. The said line was commissioned on 31.3.2012. The towers of Gaya-Fatehpur 765 kV S/C transmission line was one tower of the line (at location No. 314) had failed on 11/12.4.2012 immediately after its commissioning in March 2012. Subsequently, fifteen (15) towers [3 towers in one section, 11 towers in 2nd section and one tower in 3rd section - consecutive three sections] of above line had failed at location Nos. 305, 306, 311, 315, 320 to 330 due to heavy storm on 31.5.2014. All the failed towers were suspension towers and located in plain stretch of cultivated land. This was the second failure. Nine (9) towers had failed above bottom cross arm/waist level (near diamond section) and six (6) towers had completely collapsed

and fallen on ground. The foundations were intact. PGCIL official informed that theft of tower members was also noticed in certain tower locations. The line was restored on normal towers on 30.6.2014.

10. The Standing Committee of Experts on Tower Failure appointed by CEA in its report has recommended as under:

(i) The design of towers needs to be reviewed for further strengthening. Even though the towers were designed according to IS:802(1995), in case of more failure occurs in such lines.

(ii) The patrolling of line needs to be increased in theft prone areas in order to avoid failure due to theft of tower members. The local people should be educated by PGCIL and involved for safety of towers.

(iii) Coping of Chimneys, wherever required, needs to be done to avoid accumulation of water near stubs.

11. As per the decision of the Standing Committee, BIS was requested to take actions for (i) Revision of IS 875 for review of wind map, based on studies made by SERC in 2009 in view of frequent failures of towers in the Eastern, Northern and Western regions of the country, and (ii) adoption of design criteria of 100% transverse wind load for normal condition and 75% transverse wind load for broken wire condition for suspension towers. The Committee has also recommended for installation of

Anemometer in all sub-stations of PGCIL duly computerized for obtaining wind speed data on hourly basis.

12. In response to Commission`s direction dated 3.12.2015, CEA under its letter dated 3.12.2015 has submitted the detailed report on Failure of 765 kV Gaya-Fatehpur S/C transmission line on 31.5.2014 in which CEA has made the following recommendations:

"5.0 RECOMMENDATIONS

After the detail discussions/deliberations in the meeting held in CEA, following decisions have been taken by the Standing Committee.

(a) The towers with delta configuration shall be avoided to the extent possible in 765kV single Circuit (S/C) lines in future and as such most of the 765kV lines shall be Double Circuit (D/C) lines with vertical configuration.

(b) In absence of meteorological data, it has become difficult to assess the actual wind velocity at site of failure in order to verify with the design value of wind speed. However, the detailed analysis of structural design of suspension tower (with delta configuration) of 765kV S/C line was carried out by CPRI and PGCIL using two different softwares [STADD Pro and i-Tower]. The strengthening of suspension towers (with delta configuration) of 765kV S/C line traversing through wind Zone-4 has to be carried out as indicated below by increasing the member/section size of six (6) members and adding two (2) more redundant members. The drawing showing the member location is enclosed as **Annexure –IX.**

Member No.	**Original Member Size**	**Proposed Member Size**	**Existing No. of Bolts**	**Proposed No. of Bolts**
D13	65x65x5 (MS)	65x65x6 (MS)	2 SS - 16Ø	2 SS - 16Ø
D16	80x80x6 (MS)	90x90x6 (MS)	2 SS - 16Ø	2 SS - 16Ø
D29	70x70x5 (MS)	90x90x6 (MS)	2 SS - 16Ø	3 SS – 16Ø
M51/52	100x100x8 (HT)	110x110x8 (HT)	6 DS - 16Ø	6 DS - 16Ø
D12	75x75x6 (HT)	80x80x6 (HT)	3 SS – 16Ø	3 SS – 16Ø

New Redundant connected to M5	-	50x50x5 (MS)	-	1 SS – 16Ø
New Redundant connected to H3/H4	-	50x50x5 (MS)	-	1 SS – 16Ø

(c) Since strengthening of tower is to be done above bottom cross arm/waist level (near diamond section), long shutdown shall be required for replacement of members / sections of towers in existing line and the nature of work and the risk involved in replacement of member of towers in existing line is different from fabrication of towers afresh. The fabrication of fresh towers can be taken up easily. But replacement of members in the existing towers is very difficult and lot of risk is involved. Moreover, many of the executing agencies may not be interested to take up such difficult and risky task. Dismantling and replacement of the structural part above waist level of tower requires long shut down. Hence, such activity shall be taken up during annual maintenance in a phased manner. PGCIL has to prioritize the areas/liens where such activity can be taken up. Accordingly planning has to be done by PGCIL.

(d) The failure of seven (7) Nos. of suspension towers (with delta configuration) of Anta-Phagi 765kV S/C line in RRVPNL system was also of similar nature and design was provided by PGCIL for wind Zone-4. RRVPNL has to plan and carryout above modifications by strengthening the members as indicated above.

(e) The patrolling of line needs to be increased/intensified in theft prone areas in order to avoid failure due to theft of tower members. The local people should be educated by PGCIL and involved for safety of towers.

(f) The rate of failure of suspension towers (with delta configuration) of 765kV S/C line traversing through other wind zones (other than Wind Zone-4) and areas prone to cyclone / storm needs to be monitored. In case repeated failure is observed in those lines, similar exercise for review of design has to be taken up by PGCIL for different wind zones for suspension towers (with delta configuration) of 765kV S/C line.

(g) The regions, where frequent failures of transmission line towers are observed, need to be identified and wind data logger stations may be installed by PGCIL in those areas on priority basis. PGCIL should expedite the installation of Anemometers in substations, particularly in cyclone/high wind prone areas, as recommended earlier by the Standing Committee of experts on failure of transmission lines of 220kV and voltage level."

13. POSOCO, vide letter dated 8.4.2015, has submitted the report on Sub Synchronous Resonance (SSR). POSOCO has submitted that delayed clearance of fault on transmission line is a serious issue. Since, the fault clearance time for 400 kV and 220kV is 100 ms and 160 ms respectively, NRPCs should be directed to look into the protection related issues. POSOCO in its report on the incident of SSR has made the following recommendations:

(i) With increase in use of FSCs, HVDC, SVCs, TCSC and renewable generation, there is an increasing threat perception from Sub Synchronous Resonance phenomena.

(ii) Studies to identify SSR should be done in the planning horizon. As per the provisions of the Grid Code, “the new connection shall not cause any adverse effect on the grid. The grid shall continue to performed with specify reliability, security and quality as per Central Electricity Authority (Grid standards for operation and maintenance of transmission lines) Regulations as and when they came into force". Additional data required for SSR studies such as detailed mechanical data should be provided by the manufacturer.

(iii) Simulation capability in the area of electromagnetic transients needs to be improved both in the planning and operating horizon. Necessary capacity building and equipping the planners and operators with the necessary tools becomes extremely important.

(iv) The Transmission Planning Criteria is silent on SSR phenomena. Internationally, several power systems have elaborate standards. For instance, ERCOT proposal may be taken that all transmission system changes or generator changes shall be assessed for SSR as expensive generating equipment is involved, SSR needs to be thoroughly studied for various network scenarios including a depleted network. In the ERCOT, 5 tests have been proposed, namely (a) Topology Test: This test is performed by inspection: Does it take five or fewer outages to make a generator radial to a series cap? This test would clear number of projects, especially, those far from the series capacitors and those connecting to the lower voltage network, (b) Power flow test: This tests affected outage combinations to see whether it solve in a min load case. If the case doesn't solve or has many overloads, the outage isn't credible, (c) ERCOT SSR screening: This tests is carried out as to whether the network electrical characteristics are conducive to resonance and ERCOT performs this test as part of the transmission planning, (d) Detailed study required: If credible SSR risk exists, then a study should be performed. In lieu of a study, generator resources should obtain a letter from their manufacturer or they should rework their proposal of inter-connection to reduce risk exposure.

(v) In certain time, the event of data is not being submitted by SLDC, the generators and the transmission licensees, which results in complete analysis of the events. Therefore, all utilities should submit fine resolution data/DR/EL/SOE/DAS from their end in case of system operator has observed the

oscillation in the system. The controller parameters recording from the various HVDC/FACTS devices are required for recording. SOE from number of HVDC/FACTS were not provided which was not ascertaining the overall response of HVDC and FACTS devices towards the oscillation.

(iv) PMU is unable to detect the resonance frequency generated due to sub synchronous event as current sampling frequency of ZPMUs installed in India is 25 Hz which can detect the frequency up to 25/2 i.e. 12.5 HZ so that 50 HZ PMU sampling frequency may provide better analysis option in case SSR occurrences.

(v) Both SSR mitigation and protection measures are required. However, the mitigation measures should be such that they do not cause a much more adverse effect on the grid. The generators should be encouraged to provide protection against SSR. In addition, the following remedies should be carried out to avoid SSR problem:

(a) Install passive SSR blocking filters to stop the currents at SSR frequencies flowing through the generator step-up transformer neutral connections to ground;

(b) Install Supplemental Excitation Damping Control (SEDC) to deliver damping at the SSR frequencies;

(c) Use of torsional relays;

(d) Use of supplementary excitation control;

(e) Use of static filters in series with each phase of each main generator;

(f) Use of thyristorcyclo-converter based dynamic filters;

(g) Use of Amortisseur windings on the pole faces of the generator rotors.

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14. Based on NLDC report on "Operational Feedback on Transmission Constraints' for the quarter April to June, 2015(1st quarter of 2015), the Commission vide order dated 12.10.2015 observed that 21 no. of 400 kV and above lines and 4 No of 220 kV lines where some towers had collapsed during the first quarter of 2015 leading to line outage. The Commission further observed that out of the 25 lines, PGCIL is the owner of 17 lines and the remaining lines belong to UPPCL, RRVPNL, WBSETCL. The Commission observed that the number of tower collapse is more during the first quarter of 2015 compared to the corresponding quarter in the year 2014-15. Accordingly, PGCIL and CEA were directed to investigate into the incidences of collapse of transmission towers during the 1st quarter of 2015 and submit reports containing the reasons for tower collapse. CTU was directed to explain the reasons where the revival time of the towers have exceed 30 days. POSOCO was directed to file the details of impact of collapse of transmission towers during the 1st quarter of 2015 and the consequent line tripping on the system operation and grid security, the action taken by concerned RLDCs in this regard and the response of the constituent entities to the

directions of RLDCs. Relevant portion of said order dated 12.10.2015 is extracted as under:

> "2. The Commission vide its order dated 12.10.2015 in petition no. 10/SM/2015 observed that as per the NLDC in discharge of its responsibility under Rule 4 (j) of NLDC Rules, 2005 submitted to CEA and CTU the report on "Operational Feedback on Transmission Constraints' for the quarter April to June, 2015 (1st quarter of 2015). In para 1.6 of the report, NLDC has given a list of 21 no. of 400 kV and above lines and 4 No of 220 kV lines where some towers have collapsed during the first quarter of 2015 leading to line outage. Out of the 25 lines, POWERGRID is the owner of 17 lines and the remaining lines belong to UPPCL, RRVPNL and WBSETCL. NLDC has further stated in the report that the number of tower collapse is more during the first quarter of 2015 compared to the corresponding quarter in the year 2014-15. The relevant para of the report is extracted as under:
>
> *"Comparing the first quarter of 2014 (viz. April, May, June) and the first quarter of 2015, there is an increase in the 765 kV tower collapse/damages. The comparison table is given below. It is important that these failures are investigated thoroughly and the root cause identified and the remedial vulnerable. In the eventually that the investigations indicate that all these outages are in the nature of force majeure (which again appears improbable considering the geographically widespread nature of these incidents), it calls for a re-look at the transmission planning criteria. In case the reasons for failure are otherwise, it calls for a re-look of the operation and maintenance practices and the need to secure and protect critical infrastructure such as transmission lines."*

Voltage Level	No. of tower collapse in the first quarter in 2014-15	No. of tower collapse in the first quarter in 2015-16
765 kV	3	9
400 kV	9	12
Total	12	21

15. Petition Nos. 9/SM/2014 and 10/SM/2015 were heard together on 3.12.2015. During the course of hearing, The representative of PGCIL submitted that in case of tower failure during 1st quarter 2015-16, out of total 21 tower failure cases, one tower failed due to sinking of land, in another case main member was found broken, and other cases on account of high wind velocity/cyclone. He further submitted that the tower designs were as per the prevailing norms and CEA guidelines. All the cases were investigated in association with CEA and the report would be discussed in the meeting of Standing Committee on Tower Collapse on 8.12.2015. The representative of CEA

submitted that there are two Standing Committees, one on tower failure and another on sub-station equipment failure. All utilities/transmission licensees are required to report failure of towers of 220 kV and above. However, number of State transmission utilities and PGCIL are not reporting all failures of towers/sub-station equipments to CEA. In regard to tower collapse during the 1st quarter of 2015, out of 21 cases of tower collapse, only 03(three) preliminary reports of tower failure have been received by them.

16. PGCIL, vide ROP for hearing dated 3.12.2015, was directed to investigate the incidences of collapse of transmission towers and tripping of transmission lines in 1st quarter of 2015-16 and submit report after Board's approval. PGCIL was further directed to confirm whether the issue of tower failure was discussed in the Standing Committee meeting scheduled on 8.12.2015 including the decision taken in the meeting. CEA was directed to intimate the total number of cases where tower failures have not been intimated by PGCIL to CEA and submit the detailed report on the failure of tower as on 31.5.2014.

17. PGCIL vide its letter dated 21.1.2016 submitted the incidences of transmission tower collapse and tripping of transmission lines in 1st quarter of 2015-16 was investigated and put up the following points in the 324th meeting of Board of Directors of PGCIL held on 12.1.2016:

(a) In case of occurrence of higher velocity wind, the lower is designed which includes storm, cyclone and local phenomenon of whirlwind and gale etc. These kinds of winds are difficult to predict and take into design.

(b) Theft of tower members and generally the theft of secondary members (connected with one or two bolts) of the towers by the local people making the tower weak which gives away during storms/whirlwind/cyclones, etc;

(c) Demolishing activities by miscreants like cutting/blasting the main members of the tower which is also difficult take into account during design or construction stage.

18. PGCIL has submitted that PGCIL is carrying out patrolling to minimize tower collapse and providing the members to keep the tower complete on regular basis and special patrolling to provide missing members are carried out in months of February and March before such kind of storms/whirlwind are expected. However, the same becomes extremely difficult sometimes in highly theft prone area.

19. Since, PGCIL did not submit complete information, staff of the Commission, vide ROP for hearing dated 28.1.2016, was directed to convene a meeting with the representatives of CEA, PGCIL and POSOCO. Accordingly, staff of the Commission convened a meeting on 28.3.2016 in which the following was deliberated:

(a) With regard to IS under which towers are designed, the representative of PGCIL stated that PGCIL has got the towers built as per IS:875-1987 and IS:802-1995 which take into account basic wind speed data to some extent. However, it does not take into account localised high intensity wind conditions having narrow front which are short lived and cover small local area. The representative of PGCIL further stated that, only one type of towers, namely tower with Delta configuration, have collapsed at various locations in almost all regions of the country owing to

extraordinary wind conditions. He stated that in plain terrains, suspension towers are normally much more in number as compared to tension towers and in order to economize, the cost of transmission lines, and design of suspension towers are optimized. He stated that the tower configuration for 765 kV was modified to delta configuration to reduce RoW and the RoW requirement was reduced from 85m to 64m. Further, suspension tower with delta configuration had initially failed test but after strengthening of some of the members, the tower was retested and the tower had passed the tests. The representative of PGCIL stated that transmission lines are designed as per the prevailing Standards and new design philosophy has been modified without taking into consideration narrow front wind on tower body and 75% of wind in broken wire condition for design of suspension towers. However, PGCIL is erecting suspension towers of transmission lines being designed for narrow front wind on tower body and 75% of wind in broken wire condition considering the rate of failure of suspension towers. He stated that with the above modifications, the failure rate of suspension towers has come down.

(b) With regard to report of Standing Committee of Expert on Failure of Towers, the representative of PGCIL stated report in respect of 9/SM/2014 has already been submitted to the Commission. However, it has not been submitted before the Board of Directors of PGCIL. With regard to tower failure during 1st quarter 2015-16, the representative of PGCIL stated that out of total 21 tower failure cases, 12 lines belong to PGCIL and rest of the lines belong to the entities such as UPPCL, RRVPNL, WBSETCL and Jindal Power Ltd. He further submitted that PGCIL has

submitted summary of tower failure incidences during April, 2015 to June, 2015 after obtaining approval of Board of PGCIL. The representative of PGCIL further stated that the towers were collapsed due to high velocity wind, theft of tower members and demolishing activities. He submitted that the tower designs were as per the prevailing norms and CEA guidelines. All the cases are investigated in association with CEA and the report was discussed in the meeting of Standing Committee on Tower Failure on 8.12.2015.

20. The representative of CEA submitted that all utilities/transmission licensees are required to report failure of towers of 220 kV and above. However, number of State Transmission Utilities and PGCIL are not reporting all failures of towers/sub- station equipments to CEA. He stated that failure of towers in NR on 30.5.2014 was discussed during the meeting of the tanding Committee of Experts on Tower Failure held on 19.6.2014. He stated that in regard to tower collapse during the 1st quarter of 2015, all 21 cases of tower collapse were discussed in the Standing Committee of Experts on failure of towers held on 8.12.2015 and report in this regard is under preparation and would be submitted to the Commission. He further submitted that PGCIL has not been intimating failure of sub-station equipment as required under the Act.

21. With regard to wind speed, the representative of CEA stated that at present six wind zones are being considered for design of towers. He stated that wind speed mapping for the entire country is under further revision by BIS based on inputs from Structural Engineering Research Centre (SERC), Chennai due to change in wind speed pattern in some part of the country. The representative of CEA handed over the copy of

Report of the Standing Committee of Experts on failure of Towers during April, 2014 to July, 2014. The representative of PGCIL stated that the wind speed which caused damage to the towers are difficult to measure as measurement points are located at few specific locations whereas transmission lines have to traverse a wide area and majority of its portion are far away from such wind measuring points. He stated that there could be wide variation between the wind speeds at the actual site of tower collapsed than the measuring point of IMD. He stated that anemometer needs to be installed at all sub-station to record wind speed in different part of the country. He stated that PGCIL owns more than 200 sub-stations and PGCIL has approached SERC for consultancy to install anemometer at 5 sub-stations.

22. After conclusion of deliberations, PGCIL was directed to submit the following information:

(a) Complete report of the tower failure incidences during April, 2015 to June, 2015 submitted for Board approval during the 324th meeting of Board of Directors.

(b) O&M practices and patrolling process followed by POWERGRID for transmission lines.

(c) Comprehensive report on tower collapses

(d) Status of regular reporting of failure of transmission lines and sub-station equipment to CEA.

(e) Proposed timeline of installation of anemometer at 5 sub-stations and proposed roadmap for installation of anemometer at all sub-stations in the country.

(f) Revised wind map details.

(g) Design philosophy followed by PGCIL which is better than the Standards.

23. CEA was requested to submit report of the Standing Committee on Tower Failure held on 8.12.2015 wherein the tower collapsed in Northern Region during April, 2015 to June, 2015 (1st Qtr. of 2015-16) was discussed and submit proposal to CPRI for modification in the tower design as per modified wind zone.

24. CEA, vide letter dated 29.4.2016, has submitted the report of the Standing Committee Meeting of Experts on failure of transmission line towers during the period from October, 2014 to June, 2015. The Standing Committee, after detail discussions/deliberations in the meetings held in CEA, decided the following:

(a) The most of the failures are linked to high wind speed. CE, PSE&TD informed that about 800 (as on August 2015) wind data measurement stations have been established by National Institute of Wind Energy (NIWE), Chennai covering all parts of the country for Indian wind Power Mapping. The wind data available with NIWE may be useful to obtain actual wind speed in the areas of tower collapse. The Committee suggested CEA to arrange a meeting with NIWE, SERC, PGCIL, etc., to discuss about the usefulness of wind data collected by NIWE for wind zone mapping and estimating actual wind speed in areas where towers have collapsed.

(b) The representative of SERC informed that during the material testing, other than testing of the material properties, measurement of thickness of members should be carried out. Wide variation in thickness should not be there. The area

having minimum thickness is vulnerable to failure. He further highlighted that IS: 12427 / IS: 1367 do not specify weight of nuts/bolts, which should be an important parameter for bolt. The Committee suggested CEA to write to BIS to review IS:7215 to specify required tolerance limits in respect thickness of member and IS: 12427/IS: 1367 to specify weight of nuts/bolts as one of the parameter in addition to other parameters.

(c) The patrolling of line needs to be carried out on regular basis and special patrolling should be done in the months of February and March before onset of likely period of storm/heavy wind, etc. However, in theft prone areas, frequency of patrolling needs to be increased/intensified in order to avoid failure due to theft of tower members. The local people should be educated by PGCIL and involved for safety of towers.

(d) The wind speed mapping for the entire country is under further revision by Bureau of Indian Standards (BIS) based on inputs from Structural Engineering Research Centre (SERC), Chennai due to change in wind speed pattern in some part of the country. The committee suggested CEA to write to BIS for early revision of the wind map of the country.

25. PGCIL, vide its letter dated 13.4.2016, has submitted as under:

(a) The following practice is being followed for patrolling and maintenance of transmission lines:

(i) Ground patrolling: For identification of defects, ground patrolling of transmission lines is being carried out as per following frequency:

S. No.	Type of Terrain	Patrolling Frequency	Criteria
a	Normal terrain	4 monthly	No Vulnerability
b.	Vulnerable terrain	3 monthly	i. High capacity lines like Multi circuit lines, lines having Quadruple conductor/ single source connected with generating station/ radial feeding lines ii. Forest, hills, hill slopes containing tall trees on uphill slides iii. Theft prone, Fast tree re-growth areas -spans with bamboo, eucalyptus, casuarinas drumsticks, silver oak etc.
c.	Most Vulnerable terrain	Monthly	i. Critical land sliding ii. Insurgency/ terrorist prone area based on previous experience iii. Change of river course/ critical due to flood/ Repeated Theft Prone

(ii) Attending of defects identified during patrolling: All non-shut down nature defects identified during ground patrolling are being attended at the earliest depending upon their criticality and all shut down nature defects identified during ground patrolling are being attended immediately or during annual maintenance shutdown depending upon their criticality.

(iii) Ground patrolling after line faults: Emergency ground patrolling of affected section of the line is being carried out immediately to trace the fault and take corrective action.

(iv) Thermovision scanning to identify Hotspots: Thermovision scanning of high capacity lines and heavily loaded lines is being carried out at every five year interval and is being carried at every ten years interval. Identified

Hotspots are being attended immediately/during annual maintenance shutdown depending upon the criticality.

(v) Punctured Insulator Detection (PID): PID scanning of transmission lines, which have history of Insulator de-capping, is being carried out to identify defective insulator strings. Defective insulator strings identified through PID scanning are being replaced on priority.

(b) The following tower design philosophy is followed for design of 765 kV S/C tower type A (Delta configuration):

(i) The overhead transmission lines are subject to various loads during their life span. For the design purposes, all loads can be estimated reliably except for the climatic loads (predominant being wind load), which are dependent on correctness of the meteorological inputs. The basic wind speed data provided in the IS:875 take into account the recorded cyclones to some extent but do not account for other localized high intensity wind conditions having narrow front. As such the recorded number of events of these disturbances is small to assign any frequency. On the other hand, the devastation caused by such high intensity winds is very severe though restricted to a smaller area only. High intensity narrow front winds may strike the tower structure causing additional wind loads on tower but due to its narrow front nature it is not necessary that the full wind span get exposed to the wind.

(ii) The transmission line towers in India are generally of self-supporting

lattice steel type which are designed as per Indian Standard IS:802 Part-1 "Use of Structural Steel in Overhead Transmission Line Towers - Code of Practice , Part-1 : Materials, Loads and Permissible Stresses ". This standard was first published in 1967 and subsequently revised in 1973, 1977 and 1995.

(iii) The latest revision (in 1995), generally based on IEC-826; 1991, incorporates concept of ultimate loads. Various loads are classified into three categories, namely (a) Reliability Requirements: Climatic loads under normal conditions; (b) Security Requirements: Failure containment loads under broken wire conditions, and (c) Safety Requirements: Loads during construction and maintenance.

(iv) Basic wind speed based on peak gust velocity, averaged over 3 seconds duration, as per wind map of India given in IS:875;1987 "Code of Practice for Design Loads (other than earthquake) for Buildings and Structures, Part-3 Wind Loads" is considered for calculating reference wind speed (averaged over 10 minutes duration). Terrain and topographic factors are also taken into consideration for working out design wind speeds and the corresponding design wind pressures. The loads on conductors, insulators, earth wires and towers are calculated considering relevant Gust Response Factors, Drag Coefficients, etc.. The towers had been designed and tested accordingly before putting into use. As per IS 802-Part-1-1995, the suspension tower was to be designed for 100% wind in reliability condition and for ‘nil’ wind in security condition.

(v) In addition to existing codal provisions, the suspension towers had been designed and tested by PGCIL with 75% wind in security condition and for Narrow front wind condition. As such 765 kV S/C tower type A (Delta configuration) was designed and tested for more stringent conditions than the codal provisions.

(c) Installation of Anemometers on all substations of PGCIL**:** With reference to the installation of Anemometer in all sub-stations, matter is being taken up with Structural Engineering Research Centre (SERC), Chennai for providing consultancy to measure the wind speed and calculate the basic wind speed required for tower design, initially for 5 nos. of sub-stations. In this regard, meeting with Dr. S Selvi Rajan of SERC is scheduled in April 2016 and after the meeting timeline would be decided.

26. PGCIL was directed vide ROP for the hearing dated 28.4.2016 to submit the information with regard to (i) complete report of the tower failure incidences during April, 2015 to June, 2015 submitted for Board approval during the 324th meeting of Board of Directors, (ii) comprehensive report on tower collapses; (iii) status of regular reporting of failure of transmission lines and sub-station equipment to CEA; and (iv) Proposed timeline of installation of anemometer at 5 sub-stations and proposed roadmap for installation of anemometer at all sub-stations in the country.

27. PGCIL, vide its affidavit dated 17.5.2016, has submitted the complete report of the tower failure incidences during April, 15 to June, 15, comprehensive report on tower failure and status of regular reporting of failure of transmission lines and sub-station

equipment to CEA. With regard to proposed timeline if installation of anemometer at 5 sub-stations and proposed roadmap for installation of anemometer at all sub-station in the country, PGCIL has approached SERC, Chennai for installing weather equipment as a pilot project at PGCIL`s Nellor sub-station and a meeting in this regard was held on 12.5.2016. According to PGCIL, efforts are being made for installation of weather equipments at 05 designated sub-stations (Nellor, Bina, Sasaram, Hisar and Gazuwaka) by December, 2016 and after successful completion at all sub-stations of pilot project, roadmap for installation of anemometer at all sub-stations in the country shall be made.

Analysis and decision:

28. We have considered the rival submissions of PGCIL, POSOCO and CEA and perused the material on record and proceed to dispose of the matters. The following issues arise for our consideration:

(a) Whether suitable actions were taken during collapse of transmission towers, lines tripping and load crash on 30.05.2014 by POSOCO?

(b) Whether PGCIL has designed and erected the transmission towers as per the standards, guidelines and codes? Whether PGCIL is carrying out operation AND maintenance of transmission lines and towers as per best industry practices to prevent tower collapse incidences?

The above issues have been dealt with in succeeding paragraphs.

Issue No.1: Whether suitable actions were taken during collapse of transmission towers, lines tripping and load crash on 30.05.2014 by POSOCO?

29. We had, vide order dated 19.6.2014 in Petition No. 9/SM/2014, observed that on 30.5.2014 at 16.00 hrs to 19.00 hrs, Northern Region grid experienced heavy demand crash due to rain, dust storm/thunder storm, mainly in the States of Uttar Pradesh, Haryana, Uttarakhand and Delhi. It was noted that Northern Region demand started declining steadily at a rate of approximately 200 MW/min and reached to 32780 MW at 17.15 hrs, around 8000 MW less than the demand at corresponding time of preceding day, and the power resulted in high frequency and high voltage in the system. As per weather forecast of Indian Metrological Department and NOWCAST, all constituents of Northern Region were alerted about the likelihood of the storm. Perusal of the load crash report reveals that the storm caused damage to number of towers including 2 towers of 765 kV and one of 400 kV lines and 10 towers on various 220 kV transmission lines in Delhi. It was further noted that collapse of transmission towers and lines tripping of such a large magnitude is alarming and needs to be investigated in detail. Accordingly, POSOCO (NLDC) was directed to submit the impact of collapse of transmission towers and lines tripping on the system operation and grid security, the action taken by concerned RLDC in this regard and the response of the constituent entities to the direction of RLDC.

30. POSOCO (NLDC) vide its report dated 17.2.2014 has submitted that total 77 transmission lines tripped during the storm period, out of which the tower collapse had been reported in 18 transmission lines. NLDC has submitted that all RLDCs were informed about IMD forecast for the day by 1620 hrs. Backing down of the order of 2700 MW of generation was achieved in NR during the storm. Backing down of hydro was

done throughout the country. According to NLDC, HVDC Mundra-Mahendragarh tripped on Sub Synchronous Resonance (SSR) and number of transmission lines tripped due to thunderstorm and rainy weather conditions and grid became substantially weak and any further tripping could have led to separation of Punjab/Haryana/HP/J&K system from rest of the grid as also Uttarakhand system. NLDC has expressed its concern on delayed clearances of fault in various transmission lines and has stated that during incidents, fault clearance time up to 1200ms was observed which is much more than the CEA grid standards. NLDC has contended that after consistent follow up of NRLDC, generation backing down by respective State control area was carried out. We have considered the submissions of NLDC. In our view, NLDC took necessary actions during collapse of transmission towers, lines tripping and load crash on 30.5.2014.

31. POSOCO was directed vide ROP for hearing dated 14.10.2014 to investigate the incident of SSR, delayed generators response and delayed clearance of faults on the transmission system in consultation with CEA and submit a report in this regard. POSOCO vide its letter dated 8.4.2015 has submitted the report on Sub Synchronous Resonance (SSR) and delayed clearance of faults on the transmission system. Perusal of report submitted by POSOCO reveals that delayed clearance of fault on transmission line is a serious issue and the fault clearance time for 400 kV and 220 kV is 100ms and 160ms respectively. POSOCO has submitted that with increase use of FSCs, HVDC, SVCs, TCSC and renewable generation, there is an increasing threat perception from SSR phenomena. Both SSR mitigation and protection measures are required. The mitigation measures should be such that they do not cause a much more adverse effect

on the grid. The generators should be encouraged to provide protection against SSR. All utilities should submit fine resolution data/DR/EL/SOE/DAS from their end in case of system operator has observed the oscillation in the system.

32. We have considered the submission of POSOCO. In our view, the studies related to SSR phenomenon should be part of Transmission Planning Criteria and CEA Grid Connectivity Regulations. Therefore, CEA may examine the impact of SSR phenomenon in detail and considering inclusion of such studies in Transmission Planning Criteria and CEA Grid Connectivity Regulations to enable studies on SSR phenomenon at planning stage. Protection audit and its implementation are being monitored at the RPC level. Accordingly, we consider it appropriate to entrust the task of assessing the impact of delayed clearance of faults on the transmission system to the RPC. We direct RPCs secretariat to examine the cases of delayed clearance of faults on the transmission system during last two years in respective Region and submit an analysis report within six month from the date of issue of the order.

Issue No.2: Whether PGCIL has designed and erected the transmission towers as per the standards, guidelines and codes? Whether PGCIL is carrying out operation and maintenance of transmission lines and towers as per best industry practices to prevent tower collapse incidences?

33. The Commission, vide order dated 19.6.2014 in Petition No. 9/SM/2014 and order dated 12.10.2015 in Petition No. 10/SM/2015 expressed concern about the rising incidence of tower collapse. Accordingly, PGCIL and CEA were directed to investigate into the incidences of collapse of transmission towers and to submit the detailed report in this regard.

34. PGCIL has submitted the following reasons for tower failures:

(a) The tower design was done according to IS standards with reliability period of 50 years as per the prevailing norms and CEA guidelines. The overhead transmission lines are subjected to various loads during their life span. All loads can be estimated reliably except for the climatic loads (predominant being wind and ice load) for design purposes, which are dependent on correctness of the meteorological inputs. In NR the transmission towers are designed as per IS: 802-1995, considering wind zone-4 under IS:875 (part-3)-1987 with wind speed 47ms and takes into account the recorded cyclones to some extent but do not account for other localized high intensity wind conditions having narrow front viz. tornadoes, hurricanes, localized thunderstorms/ dust storms etc. These are short lived and cover small local areas.

(b) There is a change in wind speed pattern and wind zone given by Structure Engineering Research Centre (SERC), Chennai. However, the same has not been considered in the recently published IS: 875 code and IS: 802 code. Occurrence of higher velocity wind which includes storm, cyclone and local phenomenon of whirlwind and gale, etc. are difficult to predict and take into design.

(c) The failures in these cases can be considered as isolated event occurred in extremely high localized wind conditions. The wind speed measurement points are located at few specific/designated points whereas transmission lines have to

traverse a wide area and majority of its portion are far away from such wind measuring points. There could be wide difference between the wind speeds at the actual site of tower collapse than the measuring point installed by IMD.

(d) Theft of tower members and generally, the theft of secondary members (connected with one or two bolts) of the towers by the local people making the tower weak gives away during storms/whirlwind/ cyclones, etc.

(e) Demolishing activities by miscreants such as cutting/blasting the main members of the tower which is also difficult take into account during design or construction stage.

(f) The tower configuration for 765 kV was modified to delta configuration to reduce RoW and RoW requirement was reduced from 85m to 64m. The tower with Delta configuration has collapsed at various locations in almost all regions of the country due to extraordinary wind conditions.

(g) In plain terrains, suspension towers are normally much more in number as compared to tension towers and in order to economize the cost of transmission lines, design of suspension towers are optimized. Most of the failed towers of transmission lines are of suspension type.

35. As per CEA`s reports of Standing Committee of experts on failure of towers, towers were failed due to the following reasons:

(a) The high wind velocity during storm, cyclone and local phenomenon of whirlwind and gale, etc. might have exceeded the wind speed for which the tower is designed. This type of wind is difficult to predict. The probability of such occurrences is low and the tower design would be uneconomical if such situation is considered in the design.

(b) Theft/sabotage of tower members, generally the theft of secondary members (connected with one or two bolts) of the towers by the local people makes the tower structurally weak which ultimately leads to failure during high speed wind/ storms/whirlwind/ cyclone, etc.

(c) It is difficult to take into account demolishing activities by miscreants like cutting/blasting the main members of the tower, during design or construction stage.

(d) Number of transmission lines are in operation with towers designed according to old Indian Standards (IS: 802 -1977). Prior to 1997, transmission towers were designed considering three wind zones. However, in 1997, country was demarcated into six wind zones. Wind speed mapping for the entire country is under further revision by BIS based on inputs from Structural Engineering Research Centre (SERC), Chennai due to change in wind speed pattern in some part of the country.

(e) In some cases, although the towers have been design according to IS: 802 (1995), but 75% of wind load in broken wire condition may not have been considered for design of suspension towers.

(f) Lack of proper soil investigation and deficiency in design of foundation of towers certain times lead to failure of towers.

(g) Lack of proper protection to foundation of towers sometimes causes damage to foundation as well as the towers.

(h) Since, in plain terrains, percentage of tangent/suspension towers are normally more compared to tension/angle towers, there is tendency to optimize the design (without much safety margin in design) in order to economize the cost of transmission lines. Over the years, it has been observed that numbers of failed towers of transmission lines are of suspension type.

36. CEA has made the following recommendations in the report of the Standing Committee of experts on failure of towers:

(a) The towers with delta configuration should be avoided to the extent possible in 765 kV single Circuit (S/C) lines in future and as such number of 765 kV transmission lines should be Double Circuit (D/C) lines with vertical configuration.

(b) The design of towers should be reviewed for further strengthening, even though the transmission lines were designed according to IS:802(1995), in case of more failure occurs in future in such lines.

(c) For normal condition and 75% Transverse wind load for broken wire condition for suspension towers design criteria of 100% Transverse wind load should be adopted.

(d) The patrolling of transmission line needs to be carried out on regular basis and to be increased in theft prone areas in order to avoid failure due to theft of tower members. Special patrolling should be done in the months of February and March before onset of likely period of storm/heavy wind etc. The local people should be educated by PGCIL and involved for safety of the towers.

(e) Coping of Chimneys, wherever required, needs to be done to avoid accumulation of water near stubs.

(f) The regions, where frequent failures of transmission line towers are observed, need to be identified and wind data logger stations should be installed by PGCIL in those areas on priority basis.

(g) To install Anemometer in all sub-stations of PGCIL duly computerized, to get output of every one hour wind data.

(h) During the material testing, other than testing of the material properties, measurement of thickness of members should be carried out. Wide variation in thickness should not be there.

(i) BIS to review IS:7215 to specify required tolerance limits in respect thickness of member and IS: 12427/IS: 1367 to specify weight of nuts/ bolts as one of the parameter in addition to other parameters.

37. The representative of CEA, during the hearing on 3.12.2015 submitted that number of State transmission utilities and PGCIL are not reporting all failures of towers/sub-station equipment to CEA. Taking note of submission of CEA, we direct all STUs transmission licensees and PGCIL to report all failures of towers/sub-station equipment to CEA as per the formats provided by it.

38. According to PGCIL, the following practices are being followed to minimize tower collapse incidences:

(a) PGCIL is carrying out patrolling and providing the members to keep the tower complete on regular basis and special patrolling to provide missing members are carried out in the months of February and March before such kind of storms/whirlwind are expected. However, the same becomes extremely difficult sometimes in highly theft prone area. Further, for the new towers, re-strengthening has been done by fixing secondary member. However, for the existing tower, it was not possible due to requirement of shut down of the line.

(b) Earlier, it was 'A' type tower (Suspension) where wind condition was not taken for the broken wire cases. PGCIL is erecting suspension towers of transmission lines being designed for narrow front wind on tower body and 75%

of wind in broken wire condition considering the rate of failure of suspension towers.

(c) Anemometers need to be installed at all sub-stations to record wind speed in different part of the country and recordings maintained. PGCIL owns more than 200 sub-stations. PGCIL, has approached SERC, Chennai for installing weather equipment as a pilot project at PGCIL`S Nellor sub-station to start off the process of installation of anemometers and a meeting in this regard was convened on 12.5.2016. Efforts are being made for installation of weather equipment at 05 designated sub-stations (Nellor, Bina, Sasaram, Hisar and Gazuwaka) by December, 2016 and after successful completion at all sub-stations of pilot project, roadmap for installation of anemometer at all sub-stations in the country shall be made.

(d) 765 kV transmission line is originally designed with Right of Way of 85 meter with horizontal configuration which has been revised with 64 meter delta configuration. Later, the configuration was found to be complicated due to difficulties in the erection work. Therefore, PGCIL has decided in case of ROW issue, it would use the delta configuration of 64 meters and in other cases, horizontal configuration would be used.

39. PGCIL, vide affidavit dated 17.5.2016, has placed on record the complete report of the tower failure incidences during April, 2015 to June, 2015, comprehensive report on tower failure and status of regular reporting of failure of transmission lines and sub-stations equipment to CEA.

40. We have considered the submissions of PGCIL and CEA. The towers of transmission line are the critical part of transmission system. Increase in number of tower collapses is a serious issue. The failure of more than one transmission line towers of 400 kV and 765 kV capacities could potentially trigger a cascading grid failure, unless Special Protection Schemes are in place. In case of failure of double-circuit or multi-circuit tower, there is tripping of more than one line which leads to N-2 or even more severe contingency. We are concerned about such increase in number of tower collapses especially of 400 kV and 765 kV transmission lines.

41. The Standing Committee of experts on failure of towers has observed that certain towers have buckled from stub level leading to complete collapse of towers with/without damage to tower foundation, some towers have buckled from the top of 1st panel (normal tower) level with/without damage to tower foundation, some towers have buckled from bottom cross arm level or top cross arm or peak broken without any damage to lower portion of the tower and foundation and there are also tower failed due to sabotage/theft of tower members and some other towers failed due to falling of tree on the line during high intensity storm. We are *prima facie* of the view that there may be some deficiency in design or construction with regards to number of members used, type of material or thickness of members/bolts, etc. In our view, PGCIL needs to take a holistic view of the situation instead of focusing on individual cases of tower failure. There is need for comprehensive review of tower designs considering the changing wind regime, structural and workmanship aspects and material used.

42. PGCIL has submitted the ground patrolling and maintenance practices. Perusal of the practices being followed by PGCIL reveals that PGCIL is not taking theft of members seriously and waiting for next shutdown opportunity in existing towers for replacing or repairing of missing members. We are of the view that O&M practices followed by PGCIL also need to be reviewed for reducing incidences of towers collapse.

43. We direct PGCIL to implement the recommendations of Standing Committee of experts on failure of towers as enumerated in para 35 above with immediate effect in letter and spirit. PGCIL is further directed to submit roadmap of installation of Anemometer in its all sub-stations within three months of date of issue of the order.

44. In our view, the reasons for tower collapse need to be further investigated by an Independent Agency, preferably an academic or research institution with particular reference to the tower design and strengthening of existing towers to prevent tower failure. We direct the staff of the Commission to process the case expeditiously to entrust the investigation to an Independent Agency at the earliest after following the required procedure.

45. Petition Nos. 9/SM/2014 and 10/SM/2015 are disposed of with the above directions.

SD/-	SD/-	SD/-	SD/-
(Dr. M.K.Iyer)	**(A.S.Bakshi)**	**(A.K.Singhal)**	**(Gireesh B. Pradhan)**
Member	**Member**	**Member**	**Chairperson**