# Statistical Analysis of Power System Events In Indian Grid

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*Abstract*—**This paper presents the statistical analysis of Grid events in the Western Regional Power System of India. The major findings and recommendations derived out of the analysis provided vital inputs for prioritizing the measures to be taken for improving compliance to technical standards, improving the operation and maintenance practices, planning for equipment upgrades and ultimately in enhancing the reliability of the power system.**

***Keywords—Compliance, Grid Disturbance, Grid Event, Grid Incidence, Post Dispatch Analysis, Reliability, Risk Mitigation, Standards.***

## I. INTRODUCTION

Indian Grid is a synchronous interconnection of Eastern, Northern, Northeastern, Southern and Western Regional grids. With an installed capacity of more than 110 GW, the Western Regional grid is the largest grid among the five regional grids in India [1]. It also has the largest number of 765 kV transmission lines, Ultra Mega Power Plants (UMPP) of more than 4000 MW capacity and highest number of generating units of 830-600 MW capacity [2]. Being self-sufficient in terms of generation capacity, WR exports power to the neighboring regions and countries. Table I show some of the key features of this region.

TABLE I. KEY FEATURES OF WESTERN REGION OF INDIAN GRID

| | |
|---|---|
| **765 kV Lines (Nos.)** | 69 |
| **400 kV Lines (Nos.)** | 381 |
| **HVDC Back to Back (Nos.)** | 2 |
| **Bipolar HVDC link (Nos.)** | 2 |
| **FACTS devices (Nos.)** | 15 |
| **Units with capacity > 600 MW (Nos.)** | 43 |
| **765 kV or 400 kV Substation (Nos.)** | 148 |
| **Demand Growth Rate during 2014-15 and 2015-16** | 10 % |
| **Generation Growth rate during 2014-15 and 2015-16** | 10 % |
| **Peak Demand Met (MW)** | 45283 |
| **Average Energy Consumption (MUs/day)** | 982 |
| **Renewable Energy Penetration (% of total installed Capacity)** | 13 % |
| **System Protection Scheme (Nos.)** | 71 |

*as on 31st Dec 2015

Geographically the Western Region covers four States and two Union Territories. Multiple generation and transmission utilities have their assets integrated with Western Region. This paper presents a statistical analysis of the grid events in the Western Region during 2012-13, 2013-14, and 2014-15. It highlights the role of statistical analysis of grid events at the Regional level in reliability enhancement and risk mitigation.

## II. GRID EVENTS IN WESTERN REGION

As per the Grid Standards notified by the Central Electricity Authority, a Grid event is referred as any power system change that significantly affects the 220 kV and above network stability [3]. Grid Event is further classified into Grid Disturbance (GD) and Grid Incidence (GI). Grid Disturbance is an event that causes loss of supply of 220 kV or above system or causes loss of integrity of the grid. Grid Incidence is an event which causes rescheduling of load or generation at 220 kV and above networks.

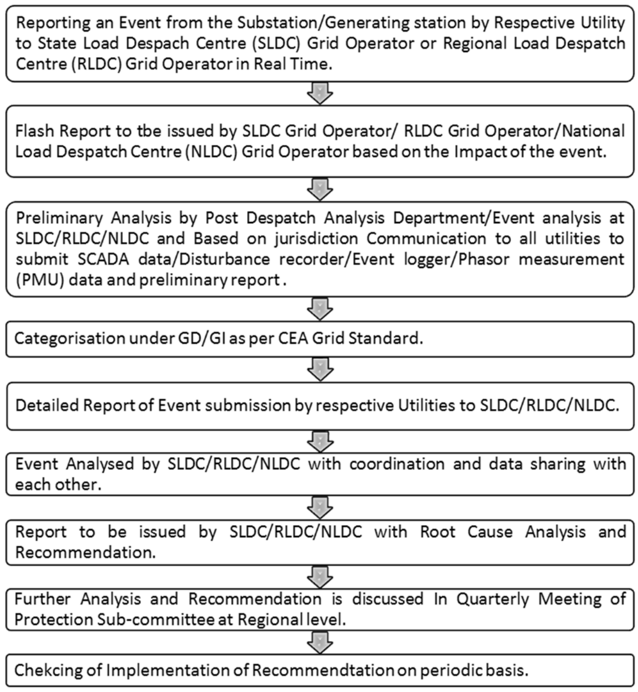


Fig. 1. Event Reporting, Categorization and Analysis Process.

Figure 1 illustrates that process of grid event analysis, adopted in the Western Region. The events are further categorized on the basis of their initiating cause [4]. Table II provides a summary of the Grid Events analyzed for the Western regional grid of India. The number of events segregated on the basis of voltage level is listed in Table III. Figure-2 presents the statistics of grid events with the various quantum of load/generation loss. Figure-3 presents the ownership-wise statistics of grid events.

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TABLE II. GRID EVENT IN WESTERN REGIONAL GRID FOR 2012-13,2013-14 AND 2014-15.

| Year | 2012-2013 | 2013-2014 | 2014-2015 |
|---|---|---|---|
| **Number of Grid Events (GD+GI)** | 80 | 106 | 157 |
| **Number of Grid Disturbance (GD)** | 36 | 47 | 60 |
| **Number of Grid Incidence(GI)** | 44 | 59 | 97 |
| **Number of GD with Generation Loss** | 24 | 38 | 21 |
| **Number of GD with load Loss** | 14 | 18 | 39 |
| **Maximum Gen Loss (MW) in any GD** | 2388 | 4030 | 1845 |
| **Maximum Load Loss (MW) in any GD** | 800 | 1295 | 1500 |

TABLE III. VOLTAGE LEVEL WISE EVENTS NUMBER IN 2012-13, 2013-14 AND 2014-15 IN WESTERN REGIONAL GRID

| Year | 2012-2013 | 2013-2014 | 2014-2015 |
|---|---|---|---|
| **400/765/HVDC** | 29 | 63 | 75 |
| **220 kV** | 51 | 43 | 82 |

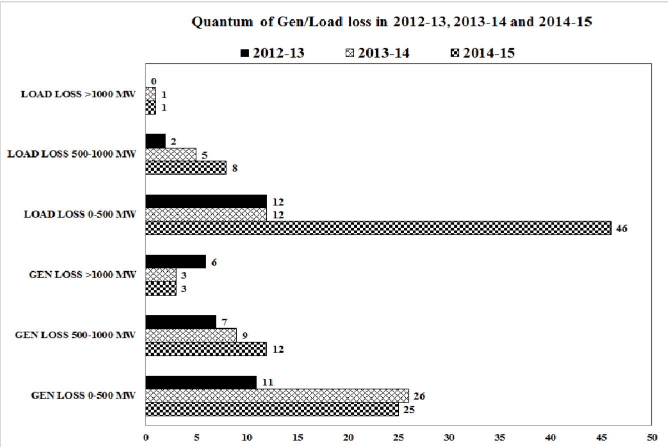


Fig. 2. Events categorisation based on load and generation loss during 2012-13, 2013-14 and 2014-15.

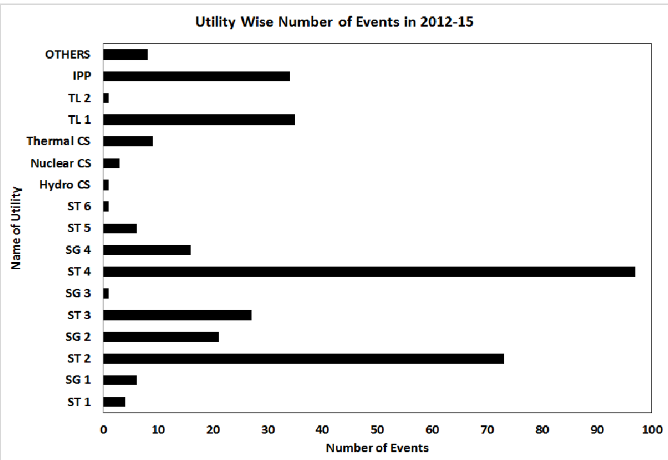


Fig. 3. Utility wise number of events during 2012-13, 2013-14 and 2014-15.( ST : State Transmission Utility; SG : State Generation Utility ; CS : Central Sector Generation Utility ; IPP :Independent Power Producer utility ;TL : Inter-State Transmission System Licensee.

The following inference can be made from the above statistics:

1. The number of Grid Events is significantly high.
2. The number of Grid Events occurring in elements under the jurisdiction of transmission utilities ST2 and ST4 is significantly higher than others.
3. The number of Grid Events occurring in elements under the jurisdiction of IPPs is higher than other generating utilities.

## III. INITIATING CAUSE OF GRID EVENTS

It was observed that the initiating cause of the Grid events could generally be clustered into eight categories as under [6, 7]:

1. Line/Power Transformer Tripping : It includes line/Power transformer tripping either on overvoltage/overflux or overcurrent protection without any fault.
2. Line/Power Transformer Fault Related Tripping: Tripping of line/Bus/Power Transformer on power system fault.
3. Bus Fault Related Tripping : Any fault on the Bus bar and it's protection zone whose cause may be instrument transformer failure, Insulator post-breakdown, circuit breaker failure etc during normal operation.
4. HVDC Tripping : This is related to HVDC Outage on filter tripping, card failure, Auxilary supply failure, Commutation failure etc.
5. Weather Related Tripping : These are attributed to rains, thunderstorm, heavy wind etc. which has caused major line/bus tripping on faults attributed to .
6. Human Factor Related Tripping : Event occurrence due to human error while performing testing and operation and maintenance activity.
7. Protection Mis-operation Related Tripping : It involves the events which started due to misoperation of protection system resulting in multiple tripping when there was no fault.
8. Other Tripping.

The cumulative number of Grid events falling under each of the above stated initiating cause in the three years is illustrated in table 4.

TABLE IV. GRID EVENTS AND THEIR INITIATING CAUSE

| Year | Total Number | Percentage |
|---|---|---|
| **Line/Power Transformer Tripping** | 26 | 7.6 |
| **Line/Power Transformer Fault Related Tripping:** | 54 | 15.7 |
| **Bus Fault Related Tripping** | 152 | 44.3 |
| **HVDC Tripping** | 13 | 3.8 |
| **Weather Related Tripping** | 16 | 4.7 |
| **Human Factor Related Tripping** | 12 | 3.5 |
| **Protection Mis-operation Related Tripping** | 65 | 19 |
| **Other Tripping** | 5 | 1.4 |

It can be observed that around 44 % of the total number of events resulted from the bus fault at the substation level. The second biggest initiating cause as observed from figure 4 was protection misoperation that constituted 19 % of the total number of events. The above inference indicates the need to review the O & M practices and protection systems in the substations. It also suggests an urgent need for the technical audit of the critical substations.

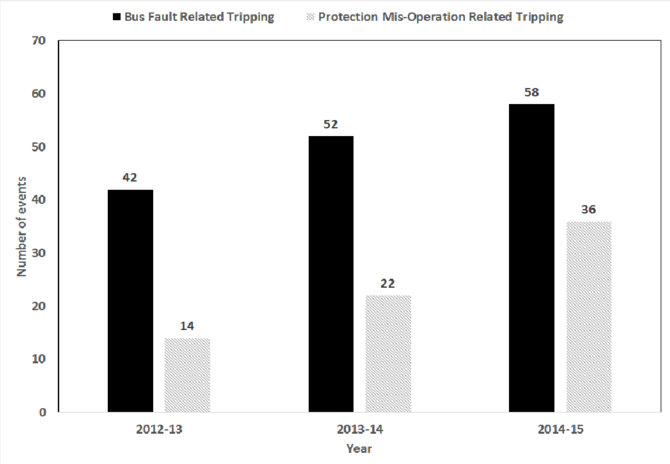


Fig. 4. Year wise number of events due to bus fault and protection misoperation during 2012-13, 2013-14 and 2014-15.

It was also noted that the found that there were 42 events of bus fault in 2012-13 which increased to 52 and 58 in subsequent years [Fig-4]. The number of events due to protection misoperation also increased from 14 in 2012-13 to 22 and 36 in subsequent years. [Fig 4]. On further probing of events associated with protection misoperation, it was found that most of them were due to static bus bar protection. Therefore, immediate steps have been taken in order that numerical schemes of bus bar protection can be adopted at 220 kV and above levels [8].

Apart from these, HVDC tripping is also of major concern due to its large number. On root cause analysis, it was found that out of the total 13 events involving HVDC tripping five were due to the auxiliary supply failure [8]. This indicates the need to thoroughly review the reliability of HVDC systems.

The next section analyses the events involving inadequacies in protection system or equipment failures.

## IV. Grid Events Attributable to Protection System Inadequacy

The utilities are mandated to comply with the Technical Standards pertaining to power system protection as stipulated by the Central Electricity Authority [9, 10]. Analysis of the events initiated due protection inadequacies revealed that they were caused by missing Busbar protection or the Local Breaker Backup (LBB) protection at 220 kV and above level substations. This was taken up with the concerned utilities, leading to some improvements as observed from figure 5.

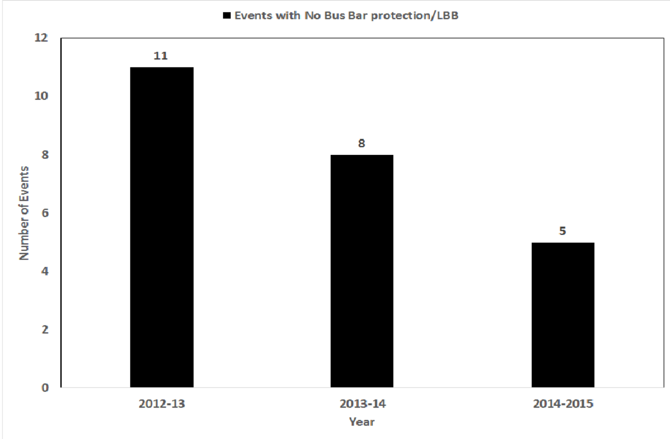


Fig. 5. Year wise number of events with no Bus bar /LBB protection during 2012-13, 2013-14 and 2014-15.

## V. Substation Equipment Failure

The failure of equipment within a substation was found to be a major cause of bus faults. These includes the failure of Circuit breaker, instrument transformer and other equipment. Equipment failure leads to damage to a nearby equipment and poses a threat to human life. Other equipment failure consists of Isolator failure/breakdown, Bus bar damage, Conductor/Jumper Snapping in the switchyard, grading Capacitor failure etc. Hence, the analysis of such factors was crucial in order to find out the gaps and to bridge them.

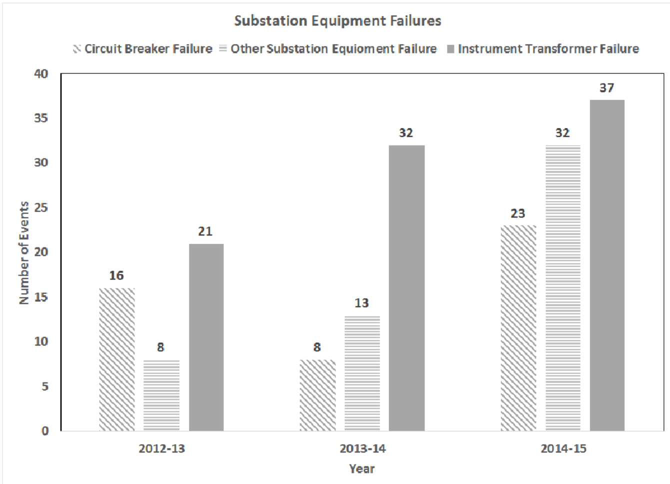


Fig. 6. Year wise number of substation equipment failures during 2012-13, 2013-14 and 2014-15.

From figure 6, it can be observed that there is an increase in the events due to substation equipment failure during the three years. Root cause analysis revealed the following reasons for these failures [8]:

1. Breaker operation above 1.06 p.u. at 400 kV and above level (High voltage stress)
2. Issues with the management of spares.
3. Deficiencies and Inadequate testing of equipment prior to installation and during their operation.

4. Failure of pantograph isolators during adverse weather condition.
5. Failure of Instrument transformers

Learning from the above analysis, all the utilities were advised to avoid switching operations when the voltage is above 1.05 p.u. Further, commissioning of controlled switching device relays for 400 kV and above connected transformer and shunt reactors were taken up progressively to reduce their failures. The utilities were also advised to review their practices with respect to the maintenance of instrument transformers.

Instrument transformer failure has increased over the year causing major bus faults in the system, which is also shown in figure 6. Therefore, it required a detailed analysis, which has been provided in next section. This is done in order to help the utilities in deriving various preventive measures reduce their failures. The next section describes the instrument transformer failures in details.

## VI. INSTRUMENT TRANSFORMER FAILURE

Instrument transformers play a major role in the power system in terms of protection, measurement and metering. Therefore, their operational reliability is very important. There were frequent cases of failure of Instrument Transformers in Western Region that caused damage to adjoining equipment sand injuries to the personnel. Such failure resulted in bus fault causing loss of several elements and supply to the consumer of loss of generation. Failure of Instrument transformer also leads to malfunctioning of protection, controls, instrumentation and power outage.

Explosive failure of Instrument transformer is caused as the result of sudden pressure and heat developed due to huge arc formation, burning and vaporization of oil/paper in small confined space.

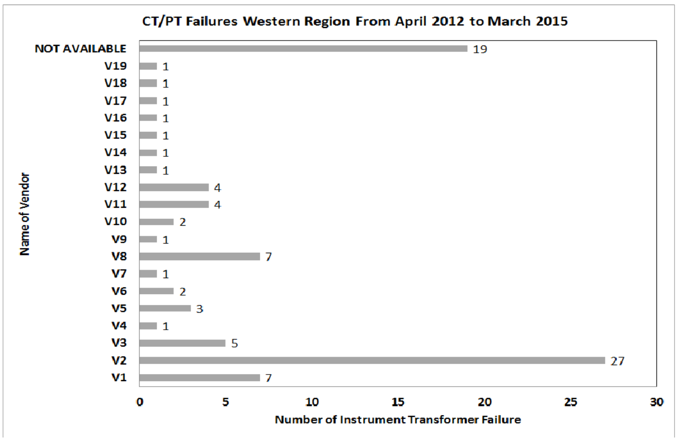


Fig. 7. Make wise Instrument Transformer failure resulting in grid events during 2012-13, 2013-14 and 2014-15.

Figure 6 shows the increase in the number of instrument transformers during the three years. While Figure 7 represents the various vendors, whose CT/PT have failed during the last three years. It can be observed that the rate of failure of one specific make of instrument transformers is higher as compared to others. The above feedback was given to utilities for suitable action.

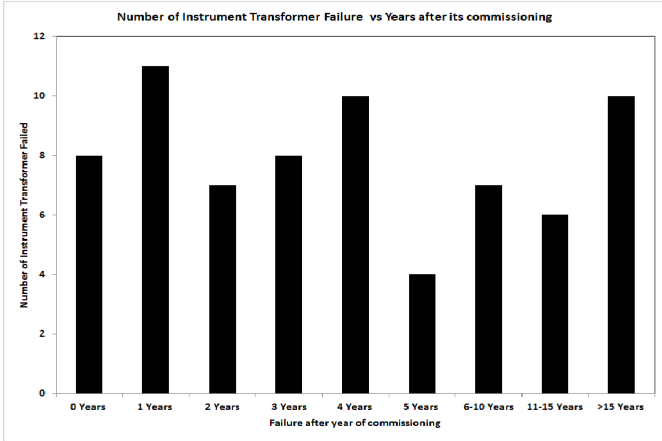


Fig. 8. Failure of instrument transformer after commissioning dates during the three years.

Further analysis of instrument transformer revealed that many of them failed within first few years of deployment [Figure 8]. The failure during first few years of commissioning could be due to manufacturing defects, transit damages, installation problems, leakages and other factors.

Failures of instrument transformer after 10-15 years are wear out failures, which are due to natural aging process resulting into dielectric degradation. Therefore, it is very important to check for the performance of CT/PT on a regular interval by testing its various parameters.

The analysis also revealed that few of the instrument transformers failed due to saturation of CT/PTs during the previous earth faults. Hence the, utilities were advised to test the CT/PT immediately after any bus fault at a substation. This has helped in prevention of severe events in the recent years.

## VII. IMPACT OF THE STATISTICAL ANALYSIS AND MEASURES TAKEN

The statistical analysis of the grid events in the Western Regional grid helped in deciding the prioritizing the remedial measures to be taken by the utilities. The summary of Grid Events was also forwarded to the planners and regulators on a quarterly basis.

A national level Task Force was constituted by the Ministry of Power, Government of India to analyze the system performance during contingencies in line with the recommendation of Grid Enquiry Committee for July 2012 disturbance [11]. The Task Force also reviewed the philosophy of operation of protection relays [12]. The recommendations and action suggested are under implementation. This will certainly help in the reducing the number of events to a large extent in the near future.

Apart from these, the central electricity regulatory commission has introduced Standards of Performance of inter-State transmission licensees regulation in 2012 where reliability indices for all inter-state transmission licensee are being computed for the protection system performance [13]. The availability certification of these lines has significantly improved the system reliability with the improved level of maintenance.

Apart from these, protection audit of more than 500 sub-stations on a wide scale has been carried out in Western Region in these years followed with its recommendation and implementation in a timeline manner to reduce events due to lack of adequate protection system.

The strict enforcement of various regulatory provisions of event reporting, analyzing and implementation of the recommendation of these reports has also been carried out in the Western Region during these years. The similar practices were also adopted across the other regional grids.

The overall impact of these actions was observed in the 2015-16 where the number of grid event has reduced to 113 which is statistically a good umber showcasing a significance declining trend.

## VIII. SUMMARY

The statistical analysis of events during the last three years 2012-2015 in the Western Regional grid has been presented in the paper. The paper has illustrated the various initiating cause for the Grid Events The analysis reveals the need for greater emphasis on O & M practices and protection system coordination. The failure of Instrument Transformers of certain make within few years of deployment indicate the need to review and address the manufacturing /material quality related issues The paper has also highlighted the areas for actions to be taken for enhancing the reliability of the system. Consequent to the various corrective measures taken by utilities, it was noted that in the year 2015-2016 the number of grid events reduced to 113.

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