Indian Experience on Impact of Leap Second in Synchrophasor Systems

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***Abstract*— Synchrophasor data is highly dependent on Global Positioning System (GPS) for its synchronized measurement as well as correct time stamping. Synchronized Time stamping is crucial when power system parameters of two or more locations are being correlated / calculated. Angular separation between any two locations of electric grid indicates the stress of the grid and is generally calculated from the phase angles measured by Phasor Measurement Units (PMU). Any time errors among these location PMUs results wide variations in angular difference pairs and may mislead the operator. In general PMU internal clock is always synchronized with GPS time, in case of time synchronization loss or drift with GPS time PMU flags the data as invalid. But during time discontinuities like leap second addition/deletion it does not flag the out-of-sync alarms. Hence, any improper handling of leap second event may distort the measurement presented to the power system operator, which may be detrimental to the power grid operation & control. This paper presents practical experiences of leap second events in Indian WAMS implemented under different pilot projects and discusses the issues associated with last three leap second events occurred on 30th June'12, 30th June'15 and 31th Dec'16. The paper also presents identification of leap second occurrence by power system operators through data and its handling by PMUs.**

***Index Terms*— Indian National Grid, Phasor Measurement Unit, leap second, Phasor Data Concentrator (PDC), Synchrophasor.**

I. INTRODUCTION

Timestamped Power System parameters are used in monitoring, control, prediction, and optimization applications. Among the main uses with the most stringent time requirements is the ability to take time-synchronized measurements using PMUs (Phasor Measurement Unit) and provide consistent reporting rates at 10, 12, 15, 20, 30, 60, or 120 frames/second, with the most common reporting rates being 25 or 50 frames per seconds in India.

Wide area time synchronization for substation measurements in the field are achieved by means of acquiring a standard reference atomic time signal through GPS in case of Synchrophasor Systems [1]. Its dependence is more critical in situations where power system parameters are derived from more than one location measurements. Any timing error would enable false conclusions about grid conditions at Control Centre, which may lead to the misdiagnosis of power system problems, incorrect response to address these problems leads to shut downs or mis operations of grid elements. Typically, angular separation between any two distinct locations of electric grid is calculated from the phase angle of these locations measured by Phasor Measurement Unit. Any time errors between these locations results in erroneous time-stamps and relative angles to bounce back and forth and may mislead the operator. Similar experiences were encountered by Indian grid operators during 2015 and 2016 leap second events.

In general, PMU has inbuilt capability of flagging the data as invalid when it loses synchronism with GPS, but leap second event does not flag loss of synchronization. Hence, if the PMU doesn't accurately account for the leap second when it happens it may introduce timing errors, and these measurements are presented to the operator which may be crucial to the power grid operation especially if these measurements are being utilized for control of power system like Wide Area Monitoring, Protection And Control (WAMPAC) applications, mis-operation of grid elements are expected to happen and in turn these shall have a catastrophic effect on grid stability.

The paper presents practical experiences of leap second event in Indian WAMS during past leap second addition events (30^{th} June 2015 & 31^{st} December 2016), it has been observed that when different make PMUs are deployed in wide area and their handling of leap second addition was different and thus creating in correct time stamps for measurements of same grid condition by drifting one second. Even some PMUs added leap second three days earlier to the scheduled insertion. The paper also presents its detection and successful handling of the same in Indian power system.

II. WAMS IN INDIA

In India, PMUs are installed on pilot basis to gain experience in Synchrophasor technology and identify the challenges that may result prior to large scale deployment of PMUs in India [3].

The PMUs are installed in all the five regions namely North, Western, Southern Eastern, and, North Eastern regions of the Indian grid at strategically selected locations like generating stations, load Centre substation, HVDC stations and major

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interconnecting substations. A total of Sixty-Six PMUs installed in India under Regional Pilot Projects. All PMUs were ultimately integrated through respective Regional PDCs (Phasor Data Concentrator) installed at Northern Regional Load Despatch Centre (NRLDC), Eastern Regional Load Despatch Centre (ERLDC), Western Regional Load Despatch Centre (WRLDC), North Eastern Regional Load Despatch Centre (NERLDC) to Central PDC installed at National Load Dispatch Centre (NLDC), New Delhi as shown in Figure-1.

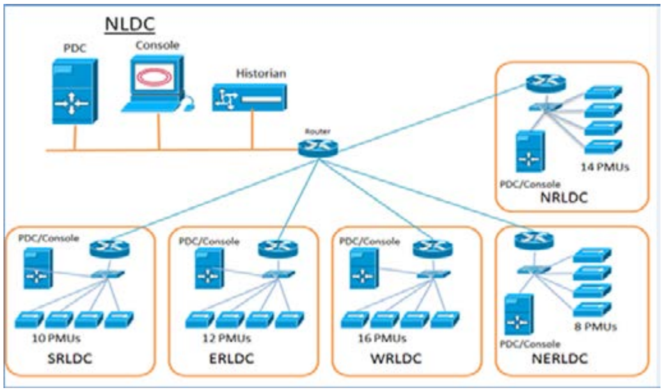

Figure 1. Architecture of Indian WAMS in 2015.

Out of the five regions, pilot project in three regions and at National level has been executed by one vendor and in other two regions pilot projects have been executed by two other vendors. A picture showing the distribution of vendors and the region in which the pilot project was executed is shown in Figure-2.

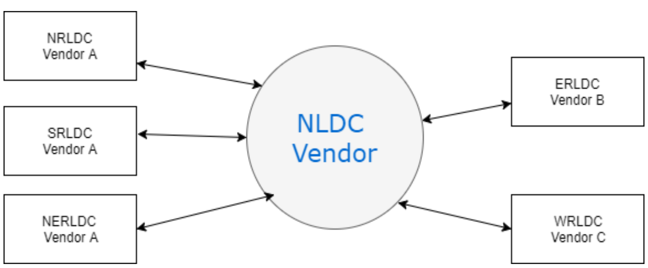

Figure 2. Vendors for pilot Projects.

PMU deployment over pan India by the end of year 2015 (including additional Gujarat state sector PMUs at 23 locations) is shown in Figure-3. PMUs supplied by two vendors are supporting IEEE Std. C37.118.2-2005 protocol whereas one vendor supporting C37.118.2-2011. All PMUs are configured to report at 25 frames per second.

Large scale implementation of Synchrophasor Technology is being installed nationwide under the Unified Real Time Dynamic State Measurement (URTDSM) project under the Smart Grid initiatives of Ministry of Power (MoP), Government of India (GoI) [4].

URTDSM system is expected to provide sub second level visibility and improve observability of dynamic conditions of Indian grid. Presently, under the URTDSM project about 1400 PMUs are expected to install and report to the Load dispatch Centre and the project is at its advanced stage of completion.

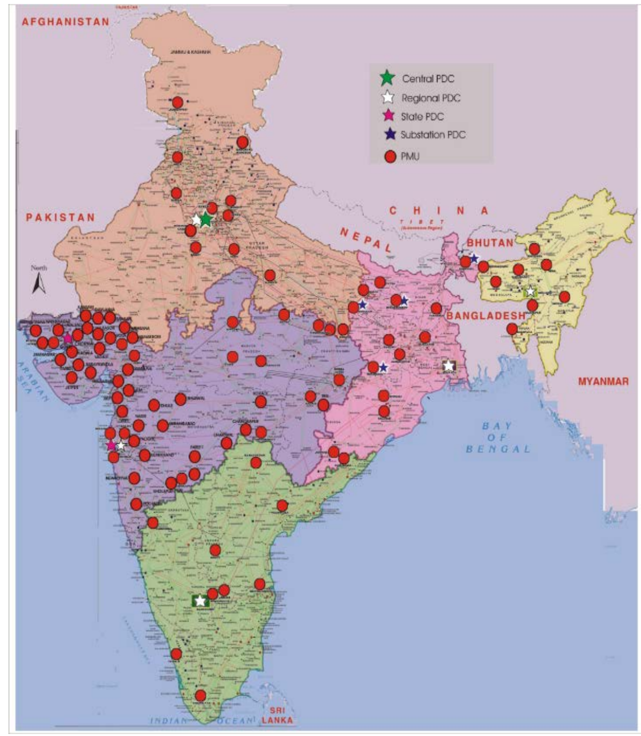

Figure 3. PMU Deployment in India by end of the year 2015.

III. BREIF BACKGROUND OF LEAP SECOND

The concept of a leap second was introduced to ensure that coordinated universal Time (UTC) would not differ by more than 0.9 second from **Universal Time (**UT1), the time determined by the rotation of the Earth — an arrangement made primarily to meet the requirements for celestial navigation [5].

INTERNATIONAL ATOMIC TIME

International Atomic Time (TAI) is the uniform time scale from which UTC is derived. It is produced at the Bureau International des Poids et Mesures (BIPM), where clock data are gathered from timing laboratories around the world. Approximately 400 clocks are used to form TAI. This information is combined to provide a time scale without a relationship to the Earth's rotational speed. No leap second adjustments are made to TAI. UTC is currently derived from TAI however, using the expression.

UTC = TAI – (10 + number of leap seconds).

Universal Time (UT1), also known as astronomical time, refers to the Earth's rotation (rotation of the earth is not constant). It is used to compare the pace provided by TAI with the actual length of a day on Earth.

TAI does not consider the Earth's slowing rotation, which determines the length of a day. For this reason, TAI is constantly compared to UT1. Before the difference between the two scales reaches 0.9 seconds, a leap second is added to UTC. Normally leap second is inserted in the last minute of either December or June, or exceptionally in March or September, immediately prior to midnight or 00:00:00 hours UTC. In recent times such leap seconds are added to UTC on 30th June 2015 at 23:59:59 hrs. UTC or 01st July 2015 05:29:59 hrs. IST and 31st December 2016 at 23:59:59 hrs. UTC or 01st January 2017 05:29:59 hrs. IST.

IV. Handling of Leap Second in PMU

According to IEEE Std. C37.118.2-2011 clause 6.22: Time and Message Time Quality [6], the most significant byte of the 32-bit Fraction of Second (FRACSEC) field in all PMU frame types is used as an 8-bit message time quality flag. The definition for this flag is in C37.118.2 as shown Table 1.

Table 1: Time Quality Definitions C37.118.2[6].

Bit #	Description
7	**Reserved**
6	**Leap Second Direction-0 for add,1 for delete**
5	**Leap Second Occurred-set in the first Second after the leap second occurs and remains set for 24h**
4	**Leap second Pending-shall be set not more than 60 s nor less than 1 s before a leap second occurs and cleared in the second after the leap second occurs**
3-0	**Message Time Quality indicator code**

Table 2 describes the Second of Century (SOC) time of the leap second has been updated to 1435708799, which is the SOC of the leap second on June 30 2015, at 23:59:59 UTC [7]. The SOC is the number of seconds which have elapsed since 00:00:00 UTC on January 1, 1970 not including the leap seconds that have occurred since then.

V. Effect of Leap Second in PMUs Installed in Indian Power System

Leap Second event in Year 2012

Though the some of the pilot projects in Northern region and Western region have encountered the leap second event in year 2012 when International Earth Rotation and Reference Systems Service (IERS) did the insertion of one second on 30th June 2012 but nothing was experienced at that time. Since, each project was isolated and have PMUs from same manufacturer, effect of leap second was not observed in data of Western & Northern regions projects. Later it was identified that Synchrophasor data of one of the projects has drifted by one second.

Leap Second event in Year 2015

In year 2015, leap second was scheduled to be added on 30th June 2015 at 23:59:59 UTC time i.e. 05:30 hrs. IST of 1st July 2015. Since, there were more numbers of PMUs of different manufacturer, with no previous experience, it was decided to be cautious on 1st July 2015. However, leap second phenomena occurred in some PMUs of one vendor three days before the scheduled addition of leap second and some PMUs added on the envisaged date.

Table 2: Example of SOC and time quality bits around leap second[7]

SOC Time	Time of day	Direction	Occurred	Pending	Comments
1435708729	23:58:59	X	0	1	Direction bit any state before pending
1435708730	23:59:00	0	0	1	Pending bit can be set no earlier than here
1435708730	23:59:01	0			
1435708798	23:59:58	0	0	1	Pending and direction bits shall be set no later than here
1435708799	23:59:59	0	0	1	Leap second occurs here
1435708799	23:59:60	0	1	0	Occurred and direction bits remain set
1435708800	00:00:00	0	1	0	
1435708801	00:00:01	0	1	0	
14357995199	23:59:59	0	1	0	
14357995199	00:00:00	X	0	0	Occurred bit must be cleared no later than here

On 28th June 2015, morning at about 05:29s hrs. Of IST, strange behavior was observed in the trend of PMU data at National control center PDC as shown in Figure 4.

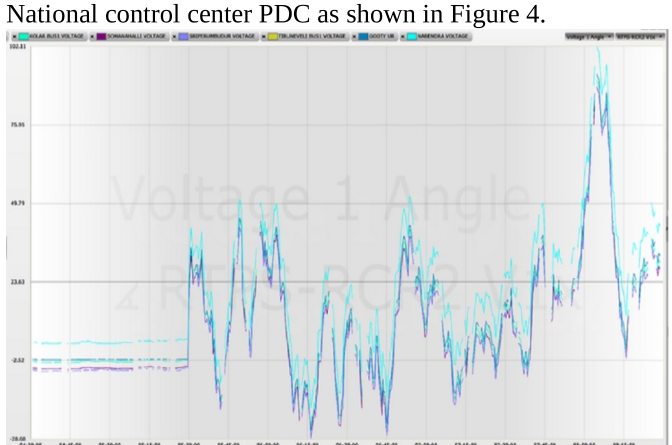

Figure 4. Real Time Angular Seperation visulisation at NLDC on 28 June 2015.

Random changes were observed in angular separation between some of the PMUs grid operators panicked as such a strange event was never experienced before. The very first task of the operator was to investigate the changes are due to power system event or due to measurement error. Real Time Operators at National & Regional control centers started enquiring with each other and after certain deliberations it was concluded that the changes were not due to any event in power system as there were no oscillations in voltage, current and frequency measurements from PMUs [8-9] and no major SCADA alarms pointing towards start of the event. Further, there were no tripping intimation from Transmission, Generation and Distribution utilities.

Hence it was suspected that the angle data from PMUs were not correct, however to substantiate the fact reference angle was changed with different combinations of angular separation in visualization software. One of the combinations was to plot same manufacturer PMU angles difference and adding other manufacture PMUs one by one. Then it was concluded that one vendor's PMU angle measurement were erroneous. Here in this case it was tried by trending the angular separation of one vendor PMU angle measurements (K & S PMUs) with respect to B PMU angle measurement, which are steady during 05:30 hrs. IST and aft wards too, later two more PMUs angle measurements form another vendor (A & R PMUs) at one of Regional Control Centre is illustrated in Figure 5.

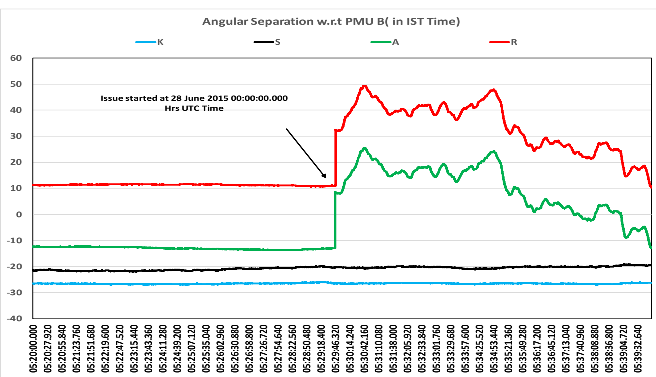

Figure 5. Relative Angle difference observed at Regional Control Centre.

In mean time an attempt was made to restart R PMU at site, the angular separation of R PMU with respect to B PMU becomes steady, event data is retrieved from historian for before, during and after restart of R PMU is plotted and shown in Figure-6

The matter was consulted with vendor, who informed that the reason for such behavior is due some bug in the software for which patch has already been released but has not been applied to these PMUs. After detailed analysis it was understood that reason for wide variation in relative angles was due to incorrect time stamps after 05:30 hrs. IST.

The incorrect time-stamp is synchronized with absolute phase angle that characterizes a different time and grid condition, then the relative angle shall produce incorrect results [10] as seen in Figure -4.

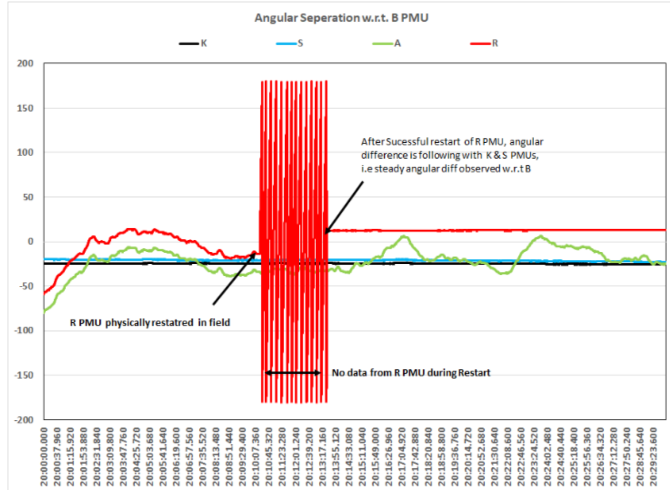

Figure 6. Angular difference during restart of faulty PMU on 28 June 2015.

Hence Incorrect timestamps due to time discontinuities such as leap seconds cause wrong presentation of grid stress while monitoring angular separation from Synchrophasor systems. Such conditions can be correctly identified and established for its true reason only when we change the reference angle measurement data for multiple scenarios one such attempt is described in Figure 5.

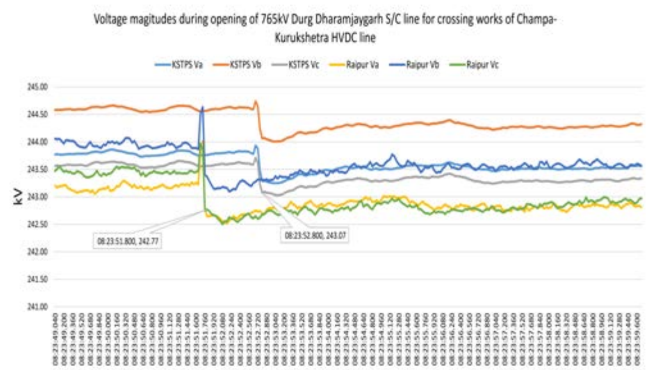

Figure 7. Time drift in voltage magnitude signal during line tripping event.

Further, as described in Table 2, PMU should repeat SOC Time 1435708799. If this does not occur, then the PMU timestamp will remain one second ahead of UTC time until something happens to reset the timestamp to the correct UTC time [7]. Here in this case restart of either GPS receiver or PMU is required as outlined above (Figure -6) in case of R PMU. Such constant time drift can be observed in voltage, current magnitudes and frequency parameters only during dynamic power system events like tripping of line or generator etc. During tripping of one major 765 kV line switching event Bus voltage magnitudes from KSTPS PMU event time 08:23:51.800 hrs. IST while Raipur PMU event time as 08:23:52.800 hrs. IST as shown in Figure 7, here Raipur PMU is having exactly one second drift in three phase voltage magnitudes compared to KSTPS PMU, thus Raipur PMU has added leap second three days earlier.

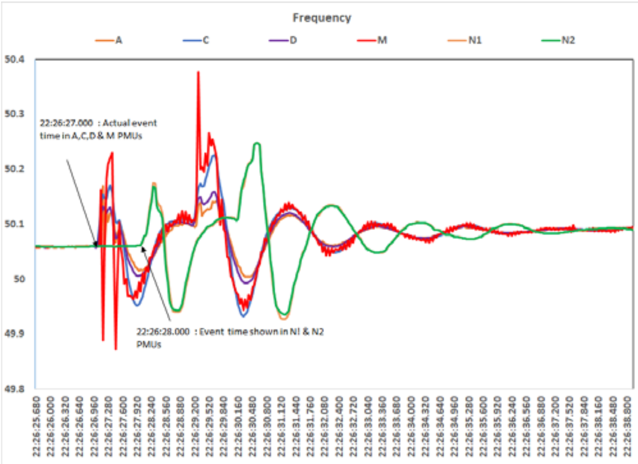

Figure 8. Time Drift in frequency measuremetn during an HVDC tripping event.

Similarly during a tripping on HVDC line frequency measuremetns from two different vendor PMUs are sown in Figure 8. Wherein frequnecy messuremetns from A,C,D &M PMUs are showing event time as 22:26:27:000 hrs. ISTand N1 & N2 PMUs are showing 22:26:2 87:000 hrs. IST, here in this case PMUs N1 & N2 are drfited by exactly one sceond.

Table 3: Summary of malfunctioned region wise PMUs

Region	No of PMUs Reporting	PMU Make		Behavior of PMU at 5:30 IST (28 June'15)
North	14	Vendor-1	13	2 PMUs Abnormal, remaining behavior is steady
		Vendor-2	01	steady
West	17	Vendor-1	03	2 PMUs Abnormal, remaining behavior is steady
		Vendor-4	12	steady
		Vendor-2	01	steady
East	12	Vendor-1	04	2 PMUs Abnormal, remaining behavior is steady
		Vendor-2	08	steady
South	12	Vendor-1	11	3 PMUs Abnormal, remaining behavior was steady
		Vendor-3	01	steady
North-East	8	Vendor-1	08	1 PMU Abnormal, other behavior was steady

From above observations and abnormal behavior start timing i.e 5:30 hrs. of IST and problem with one manufacturer PMUs it was concluded that some of the PMUs have added leap second in three-day advance i.e. on 28th June 2015 itself instead of 1st July 2015. It was also found that PMUs, which added leap second on 28th June'15, belongs to single manufacture in every region. Numbers of PMUs malfunctioned in different regions are listed in Table-3.

Interestingly during the same event, some PMUs stopped reporting to WAMS visualization software from PDC at NLDC exactly at 05:30 hrs. IST can be seen in below Figure 9. It is mainly because three days ahead addition of leap second by one vendor PMUs, all other vendors delayed because of excessive latency (slow delivery) to a PDC and in this case the latency due to incorrect timestamp was more than the PDC wait time for application, hence PDC dropped this set of PMUs to visualization application, because of late arrival due to incorrect time stamp, and not aggregated and delivered to the application for analysis.

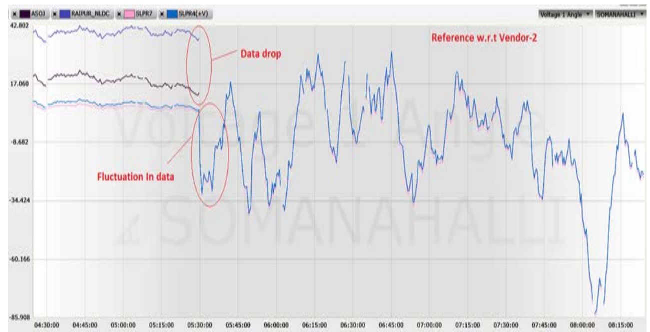

Figure 9. Non-availability of Data 05:30 IST on 28.06.2015.

On 1st July 05:29 IST i.e 30 June 2015 23:59 UTC (scheduled leap second addition), PMUs added leap seconds differently by each vendor and are summarised below:

i. PMUs which added leap second at 05:29:59.000 IST

ii. PMUs which added leap second 05:30:00.000 IST

iii. PMUs which added leap second 05:30:03.000 IST

Apart from the above, some PMUs didn't add any of leap second. Figure 10 shows the absolute angle plot during the scheduled leap second addition on 1st July 2015.

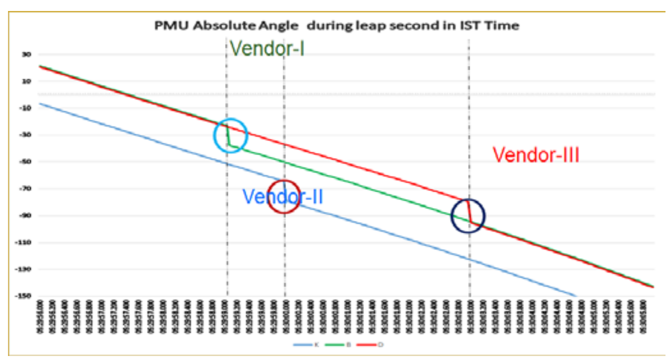

Figure 10. Absolute Angles from PMUs during leap second addition at 05:30 IST on 01.07.2015.

Vendor-I PMU responded the leap second as per actual time i.e. 23:59:00, vendor-II added leap second at 00:00:00 (after one second) and vendor-III PMU added leap second at 00:00:03 (after four second).

Leap Second event in Year 2016

Based on the 2015 leap second experience, precautionary action taken and confirmation from each vendor was sought for proper handling of leap second. Each one has also confirmed about it; however, two PMUs of same vendor again mishandled the leap insertion of leap second. Again, issue resolved by restarting of GPS system. Reason for such misbehave from vendor is still awaited. However apart from one vendor all other vendor PMUs have added leap second, snapshots for the 2016 leap second event for vendor I & II are same like earlier leap second event in 2015 is shown in Figure 11.

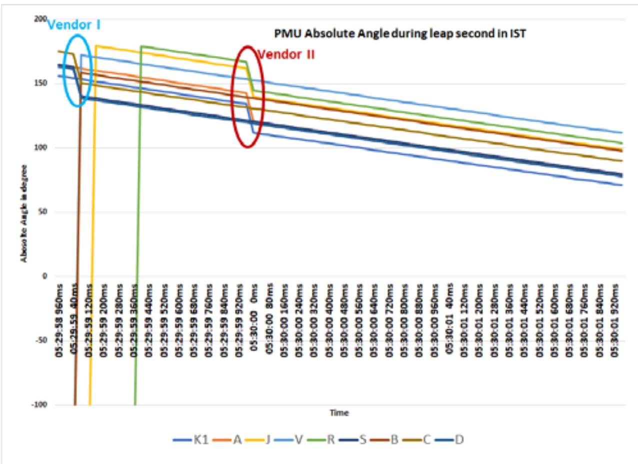

Figure 11. Absolute Angles from PMUs during leap second addition at 05:30 IST on 01.01.2017 IST

VI. Summary And Conclusion

This paper presents how PMUs of different manufacturer responded differently to leap second event although all manufacturers claim to be capable to handle leap second event. The improper handling of leap second may result to distortion of angular difference (mainly) which shows erratic values even in steady state and it can create panic situation amongst operators. However due to mishandling of leap second creates a drift in other measured parameters like frequency, voltage and current magnitudes etc. does not show any significant change during power system quasi steady state.

Unified Real Time Dynamic State Measurement (URTDSM) project for pan India installation of about 1400 PMUs and 34 Control Centre WAMS infrastructure are under commissioning and expected to fully operational shortly. With such large volume of PMUs, wrong handling of leap-second would lead to missing data and/or the failure to create data frames. The failure to deliver data to concentrators and applications within acceptable latency periods causes data gaps that could obscure early warning information about dynamic grid conditions.

WAMPAC Applications such as anti-islanding and demand response that would provide voltage and frequency stability with potential presence of dynamically variable loads and generation sources utilize PMUs as input in deriving the meaningful actions. Leap second events and mis-handling of leap seconds may affect the result of application. It is here to mention that the actions of SPS, Rapid Action Protection System (RAPS) and Wide Area Monitoring, Protection and Control (WAMPAC) controllers based on PMU could have triggered some undesired tripping in the event of time discontinuities inserted by leap second. Hence it is appropriate to ensure and testing of the handling the leap second by PMU vendors before implementing WAMPAC controllers in the field.

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