# Experience of commissioning of PMUs Pilot Project in the Northern Region of India

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*Abstract*—**Indian power sector is expanding at a fast pace in order to achieve its goal of "Electricity for All by 2012". For decades, traditional SCADA measurements have been providing information on bus voltages, line, generator & transformer flows (MW, MVAR & Amperes), transformer taps & breaker status as well as other system parameters viz, frequency and weather data. These measurements are typically taken once every 4 or 10 seconds offering a steady state view of the power system behavior. However, for monitoring and control of such large grid only steady state information may not be sufficient. Synchrophasor Measurement technology provides dynamic view of the grid along with information like load angle between different locations of the grid. Since Phasor Measurement Unit is a new technology which is still evolving; a pilot project has been implemented in Northern Region (NR) in India by Power grid Corporation of India Ltd in order to gain firsthand experience in use of this technology for monitoring and control of large power grids. This paper presents the details about the planning and implementation of this pilot project.**

***Index Terms*—Power system, PMU, Synchrophasor, SCADA**

## I. INTRODUCTION

Indian power grid is expanding at a fast pace to achieve its goal of "Electricity for all by 2012". In order to achieve this, regional grids of Indian power system are being connected synchronously to help in seamless transfer of power from one region to another. As on date four out of five regional grids in India viz Northern, Western, Eastern and North-Eastern grids have been synchronized with one another and in near future the remaining Southern grid is also to be synchronized with these grids. This however has also increased the complexity towards the monitoring and control of such large grid. Such widely spread grid requires wide area monitoring which may only be possible by emerging technologies like Synchrophasors/PMUs. Therefore, deployment of these technologies in India have been envisaged in the Government of India report "Working Group on Power for 11th Plan" as well as in National Electricity Policy.[1]

The existing SCADA/EMS technology has the capability to provide only steady state view of the power grid. Synchrophasor measurements over wide-area facilitate dynamic real time visualization of power system and are useful in monitoring safety and security of the grid in an effective manner. Synchrophasor measurements are provided by PMUs located strategically at substations/generating stations in the grid. Availability of these measurements enable us to understand the behavior of the power system under different conditions and with this better utilization of the power system can be achieved without compromising on the reliability front.

Northern Regional grid is a large grid and deploying a full-fledged scheme having PMUs across the length and breadth of the whole grid would have involved considerable time and huge investment. Therefore, in order to have some initial experiences on the subject in a fast manner, a Pilot project was initiated in the Northern Region on PMU Measurements in middle of the year 2009. The outline of this pilot project and experiences gained from the implementation of the Pilot project are detailed out in subsequent paras.

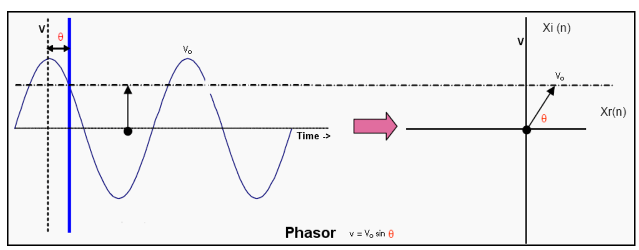


Fig. 1 - Phasor represents magnitude and phase angle at any given instant of sine wave of voltage or current.[2]

## II. PHASOR AND SYNCHROPHASOR TECHNOLOGY

A phasor is a complex number that represents both the magnitude and phase angle of the sine waves found in electricity as shown in figure 1.

Phasor measurements that occur at the same time are called "synchrophasors" and can be measured precisely from devices

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called phasor measurement units (PMUs). PMU measurements are taken at high speed typically 25 or 50 observations per second – compared to one every 4 to 10 seconds using conventional technology. Each measurement is time-stamped according to a common time reference. Time stamping allows synchrophasors from different locations to be time-aligned (or "synchronized") providing combined and comprehensive view of the entire grid. Synchrophasors enable a better indication of grid stress, and can be used to trigger corrective actions to maintain reliability.

Synchrophasor data could be used to allow power flow up to a line's dynamic limit instead of to its worst case limit. Therefore this technology has the potential to change the economics of power delivery by allowing optimum level of power flow over existing lines.

A typical PMU installation as a part of wide area monitoring system (WAMS) network consists of phasor measurement units (PMUs) dispersed throughout the electricity grid at strategic locations in order to cover the diverse footprint of the grid. A Phasor Data Concentrator (PDC) at central location collects the information from PMUs and pass it to Supervisory Control and Data Acquisition (SCADA) system after time aligning the same. The complete WAMS network requires rapid data transfer within the frequency of sampling of the phasor data. Samples of phasor measurements at PMU are time stamped at each location. The GPS installed at PMU locations provide accurate time along with time synchronization among different PMUs.

## III. PMU Installations Worldwide

The Bonneville Power Administration (BPA) is the first utility to implement comprehensive adoption of synchrophasors in its wide-area monitoring system. Today there are several implementations underway.[3]

The FNET project operated by Virginia Tech and the University of Tennessee utilizes a network of approximately 80 low-cost, high-precision Frequency Disturbance Recorders to collect Synchrophasors data from the U.S. power grid.[4]

China has also been using PMU technology in a big way. In 2006, China's Wide Area Monitoring Systems (WAMS) for its 6 grids had 300 PMUs installed mainly at 500 kV and 330 kV substations and power plants. By 2012, China plans to have PMUs at all 500kV substations and all power plants of 300MW and above. Since 2002, China has built its own PMUs to its own national standard. One type has higher sampling rates than typical and is used in power plants to measure rotor angle of the generator, reporting excitation voltage, excitation current, valve position, and output of the power system stabilizer (PSS). All PMUs are connected via private network, and samples are received within 40 ms on average.[5]

The Eastern Interconnect Phasor Project (EIPP) (now known as the North American Synchrophasor Initiative, or NASPI), has over 40 connected phasor measurement units collecting data into a "Super Phasor Data Concentrator" system centered at Tennessee Valley Authority (TVA).[6]

## IV. Existing Phasor Measurement in India

Load Despatch Centers (RLDCs) in India, being operated by Power Grid Corporation of India/state utilities, have been provided with state of the art SCADA system. SCADA at each RLDC data of different sub-stations and power plant is being received and being utilized in day to day operations of the regional grid.

To monitor the power flow between two pockets in the electric grid real time monitoring of angular separation between them is extremely useful. Existing SCADA technology does not have phase angle as an analog measurement. Hence, it was not possible to telemeter the phase angle separation between two distant nodes in the grid. Therefore, angular separation between pockets was calculated at the control centre with the help of real time power flow, bus voltages and network reactance using standard equation $\delta = \sin -1 (P*X/V1*V2)$.

The system operators make efforts to maintain this separation within the limits derived from past experience of system separations. Actions taken based on these phase angle displays probably prevented occurrence of several grid disturbances.

However, this method of phase angle calculation has limitations due to uncertainty in data availability from RTU stations and updation time of 10-15 seconds, which is considerably large from the point of view of power system dynamics.[7][8]

## V. Details of PMU Pilot Project in NR, India

The PMU pilot project implemented in Northern Region (NR), India consists of PMUs along with GPSs installed at selected 4 substations of the northern regional grid and a Phasor Data Concentrator and other associated equipments at

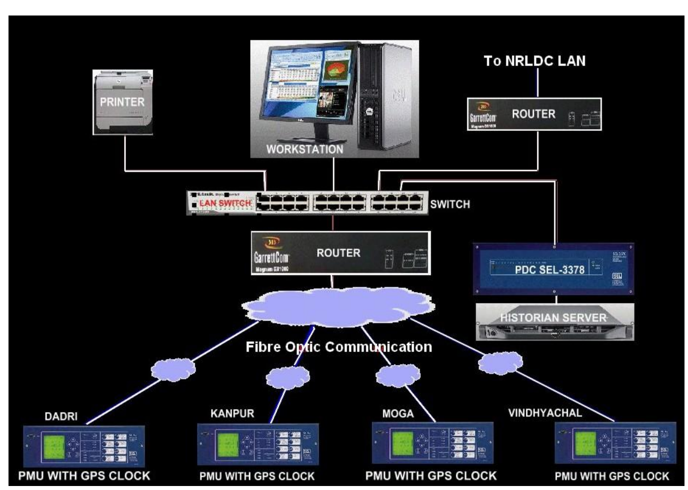


Fig 2 - Hardware architecture of pilot project.

Northern Regional Load Deaspatch Center (NRLDC) located at New Delhi. Hardware configuration of the pilot project has been shown in Fig 2.

The locations where PMUs have been provided are Vindhychal HVDC, 400 KV s/s Kanpur, Dadri HVDC and 400KV s/s Moga. PMU at each location is presently taking one 3-phase voltage input and one 3-phase current input. Voltage inputs have been provided from CVT/PT of one of the main bus of the substation.

PDC and associated equipments installed at NRLDC is shown in Fig 3 and PMU and GPS as installed at one of the location are shown in Fig 4.


Fig 3 - PDC and other equipments at NRLDC


Fig 4 - PMU and GPS at Sub-station

The phasor data at each PMU is being sampled at 25 samples per second. This phasor data is time stamped and transferred to phasor data concentrator (PDC) provided at Northern Regional Load Despatch Center NLRDC through dedicated 64 Kbps fiber optic communication channel.

The phasor data received from all the locations is merged and time aligned in PDC provided. The time aligned data from PDC is provided to operator console for visualization. The visualization display on an operator console is shown in Fig 5. PDC data is also fed to a data historian provided at NRLDC. Data from historian can be made available to external database through ODBC (Open Database Connectivity) and spreadsheet for further analysis. The PDC has also been provided with OPC (OLE for Process Control) server in order to transfer real time phasor data to existing SCADA system. Communication between PMUs at remote locations and PDC at central location takes place as per IEEE C37.118.

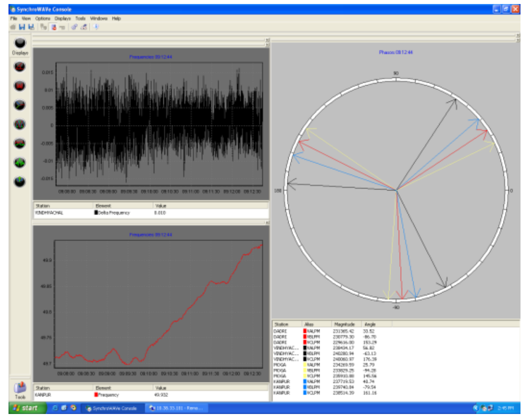

Fig 5 - Data Visualization at NRLDC.

The main elements of the system are as follows:

- Phasor Measurement Units having one 3-phase voltage input, one 3-phase current input at each location.
- GPS with 1 micro second accuracy at each location.
- Phasor Data Concentrator capable to follow IEEE C37.118 protocol along with a historian at central location. PDC was required to have OPC server for transfer of data to existing SCADA and other analysis tolls like spreadsheet etc.
- A operator console with visualization software for phasors for central location.
- LAN with router, switches and cabling etc.
- Communication channels between PMU locations
- and NRLDC.
- Communication interface converters for interfacing with existing fiber optic channels.

## VI. Selection of Locations

Considering that it is a pilot project involving only few locations, selection of the locations has been done on a heuristic approach. A broad criteria for selection of PMU locations is:

- Reasonably far off nodes to get a wider footprint.
- close to large generating complex
- Availability of fast communication from the PMU location to NRLDC.

A steady state power flow simulation for both high hydro and low hydro conditions has been carried out by NRLDC and the phase angles for each 400 kV bus considering Dadri as the reference bus has been tabulated. The results of phase angles at different locations have been shown in Table 1. The PMU locations have been picked from the different groups considering the broad criteria mentioned above. Based on this the following locations were selected:

1. Vindhyachal HVDC
2. 400 KV s/s Kanpur
3. Dadri HVDC
4. 400KV s/s Moga

## VII. Preparation of Technical Requirements

As no previous exposure or experience was available with us in the area of implementation of PMU project, a detailed exercise was took up for making our technical requirements generic and easy to implement. A strategy of using the equipments which are easily available off-the-shelf i.e without the any requirement of special manufacturing. An initial request for proposal was sent to the various SCADA vendors who have their presence in India and are already providing the SCADA systems. Responses received from these vendors were critically examined in view of the followings:-

- Wider participation of vendors.
- Readily available equipments.
- Implementation time.
- Cost of the project.

An initial draft was prepared. The draft was further fined tuned by way of discussions with users and implementers of the SCADA system in Powergrid with the view that the pilot project should meet the requirements of real time load angle visualization, archiving of PMU data for post event analysis and transfer of data to existing SCADA system.

## VIII. Commissioning of the Project

The work of pilot project was awarded in January 2010 with completion time of 4 months. After the award, the vendor immediately took up the design and engineering work of the project. PMUs and others equipments were made available at site by first week of April 2010. Installation work on all locations completed in by mid April and by the end of April 2010 data from all the locations is being received at NRLDC.

## IX. Utilization of PMU data

With the commissioning of this pilot project now phasor data from different locations available at NRLDC and to existing SCADA system. From the phasor data received form PMUs, load angle between different pockets of the grid is available more accurately with updation time of the order of few milliseconds and this will enhance the tools available to grid operator.

TABLE 1
Outcome of Study Conducted to Decide PMU Location

| Bus no. | 400 kV Bus | Actual Voltage kV | Angle (w.r.t. Dadri) | | PMU location |
|---|---|---|---|---|---|
| | | | Under High Hydro Condition | Under Winter off-peak condition | |
| 18423 | Singrauli | 420 | 32 | 28 | |
| 18432 | Vindhyachal | 420 | 32 | 28 | Yes |
| 18433 | Rihand | 416 | 32 | 27 | |
| 17468 | Anpara | 420 | 31 | 28 | |
| 17472 | Obra | 416 | 31 | 27 | |
| 17480 | Sarnath | 421 | 26 | 25 | |
| 17482 | Azamgarh | 423 | 23 | 26 | |
| 18427 | Gorakhpur_PG | 425 | 23 | 27 | |
| 17427 | Gorakhpur_UP | 425 | 23 | 26 | |
| 17486 | Mau | 425 | 23 | 28 | |
| 18475 | Balia | 426 | 23 | 28 | |
| 18474 | Allahabad | 417 | 23 | 20 | |
| 17485 | Sultanpur | 417 | 22 | 23 | |
| 18437 | Lucknow_PG | 415 | 16 | 14 | |
| 17437 | Lucknow_UP | 409 | 14 | 13 | |
| 17401 | Unnao | 408 | 14 | 2 | |
| 17466 | Panki | 403 | 13 | 11 | |
| 18431 | Kanpur | 403 | 12 | 11 | Yes |
| 18426 | Auraiya | 405 | 9 | 8 | |
| 19402 | Baspa | 412 | 9 | -5 | |
| 18403 | Jhakri | 412 | 8 | -5 | |
| 18462 | Mainpuri | 397 | 8 | | |
| 17447 | Vishnuprayag | 400 | 8 | 3 | |
| 18499 | Tehri | 404 | 7 | -3 | |
| 17402 | Bareli_UP | 394 | 6 | | |
| 18406 | Bareli_PG | 394 | 6 | | |
| 12419 | Dehar | 410 | 4 | | |
| 18422 | Agra_PG | 397 | 3 | 1 | |
| 16457 | Suratgarh | 410 | 2 | 0 | |
| 17400 | Agra_UP | 395 | 2 | 1 | |
| 17440 | Muradabad | 390 | 2 | 1 | |
| 12418 | Dulhasti | 416 | 1 | | |
| 18402 | Nalagarh | 398 | 1 | | |
| 11414 | Uri | 404 | 0 | | |
| 17446 | Muradnagar | 389 | 0 | -1 | |
| 18424 | Dadri | 389 | 0 | 0 | Yes |
| 18405 | Meerut | 388 | 0 | -3 | |
| 17445 | Muzaffarnagar | 388 | 0 | -3 | |
| 11401 | Chamera-II | 412 | -1 | | |
| 17467 | Kashipur | 392 | -1 | | |
| 18401 | Abdullapur | 397 | -1 | -5 | |
| 18436 | GreaterNOIDA | 387 | -1 | | |
| 11411 | Chamera-I | 408 | -1 | | |
| 14409 | Panipat | 393 | -1 | -3 | |
| 17425 | Roorkee | 390 | -1 | -3 | |
| 18435 | Mandaula | 388 | -2 | -2 | |
| 18428 | Maharanibagh | 387 | -2 | -1 | |
| 18419 | Ballabgarh | 388 | -2 | -1 | |
| 17426 | Rishikesh | 390 | -2 | -4 | |
| 18400 | Wagoora | 401 | -3 | | |
| 12401 | Baghlihar | 408 | -3 | | |
| 15427 | Bawana | 388 | -3 | | |
| 12422 | Kishenpur | 407 | -3 | | |
| 15428 | Bamnauli | 385 | -3 | | |
| 16408 | Ratangarh | 404 | -4 | | |
| 18434 | Bahadurgarh | 387 | -5 | | |
| 18421 | Bhiwadi | 391 | -5 | | |
| 18404 | Kaithal | 391 | -6 | | |
| 12420 | Bhiwani | 390 | -6 | | |
| 18442 | Patiala | 388 | -6 | | |
| 18430 | Bassi | 392 | -6 | | |
| 12421 | Hisar | 390 | -6 | | |
| 18418 | Jallandhar | 394 | -7 | | |
| 18425 | Malekotla | 387 | -8 | | |
| 12423 | Moga | 391 | -8 | | Yes |
| 18417 | Ludhiana | 389 | -8 | | |
| 12417 | Fatehabad | 385 | -8 | | |
| 16406 | Heerapura | 391 | -8 | | |
| 18408 | Amritsar | 389 | -9 | | |
| 16400 | Merta | 403 | -12 | | |
| 16404 | Kankroli | 406 | -12 | | |
| 16405 | RAPS_C | 412 | -12 | | |
| 16407 | Kota_PG | 412 | -12 | | |
| 16433 | Jodhpur | 399 | -15 | | |
| **Maximum** | | | **32** | **28** | |
| **Minimum** | | | **-15** | **-5** | |
| **Range** | | | **47** | **33** | |

The data historian provided is collecting concentrated data from PDC and will be useful for post event analysis of any grid incidences.

Probable applications of phasor data in future may be:-

1. Improved situational awareness.
2. Optimization towards corridor availability.
3. Load shedding and other load control techniques such as demand response mechanisms to manage a power system.
4. Increase the reliability of the power grid by detecting faults early, allowing for isolation of operative system, and the prevention of power outages.
5. Wide Area measurement and control, in very wide area super grids, regional transmission networks, and local distribution grids.
6. Increase power quality by precise analysis and automated correction of sources of system degradation.
7. Network model validation.
8. Monitoring of Inter-area oscillations.

## X. Future Directions

As of now pilot project has minimum configuration i.e 4 PMUs only. Shortly, 4 more PMU locations will be added to the existing system. PDC is already capable of taking inputs from more PMUs. Presently selected PMU locations are from within the region, however, subsequently while adding additional PMUs, subject to the availability of communication channels and other logistics, possibility of selecting the locations outside the northern region may also be explored.

## XI. Conclusion

The pilot project has been implemented in a very limited time frame and the whole work of concept to commissioning has been completed just within a period of one year. Similar to this project, project initiatives by other RLDC are also in pipe line. Experiences gained during implementation of these projects and during utilization of phasor data shall be of great help for the power sector of India.

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