Challenges faced and Lessons Learnt in Implementation of First Synchrophasors Project in the Northern India

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Abstract: Indian power sector has a mission of providing reliable, quality and affordable power for all by the year 2012. It would require enhancement of installed generation capacity at least to 200 GW by 2012. As per an estimate, power requirement will be doubled by 2020 i.e. to 400 GW. To transmit this power matching transmission highways are under way on national level and reliable delivery of such huge power across the length and breadth of the country may only be possible with the use of new and enhanced measurement and monitoring technologies.

Synchrophasors measurement is a new technology that provides a tool to system operators to measure the monitor the large grid by providing dynamic view of the grid in contrast to steady state view as provided by existing SCADA technology. Synchrophasors are accurate, time synchronised and time stamped measurement of the voltages and currents measured by the devices called phasor measurement units (PMU) located at the diverse points in the grid. These measurements are time aligned at central places by Phasor Data Concentrator and are used for visualization and monitoring of dynamic state of the electric grid.

Implementation of a synchrophasors measurement and monitoring system involves discreet stages with expert and informed decision at each stage and the whole process involves a considerable time period. Therefore in order to have a feel of the synchrophasor measurement system in the Northern Region a "pilot project has been implemented and it is envisaged that similar projects would be implemented in other regions also and gradually these projects would be scaled up and integrated in order to achieve an effective wide area measurement system (WAMS) in Indiaan Power System. It is the first pilot project of this type implemented in the Northern Region (NR) in India by Northern Regional Load Despatch Centre (NRLDC).

This paper discusses the issue and challenges faced, trade-offs made and lesson learnt during installation, commissioning of this pilot project.

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1. Introduction

In order to achieve the mission of providing power for all by 2012, it is envisaged to enhance the generation capacity by the end of the 11th plan (year 2007-2012) to a level of 200 GW along with commensurate increase in the transmission capacity. Construction of transmission super highways all along the country and formation of National Grid by synchronizing its regional grids are some of the salient features of the objective "Power for all by 2012" set by the Government of India. As on date four out of five regional grids in India viz. Northern, Western, Eastern and North-Eastern grids have already been synchronized with one another and in near future the Southern grid is also going to be synchronized with these grids. This however has also increased the complexity towards the monitoring and control of such large and widely spread grid. Traditionally SCADA system is being used for monitoring and control of the electric power grids and it provides measurements of grid parameters typically at the interval of 4 to 5 seconds, and under certain situations this time interval may further increase due to communication and other factors In a large grid where monitoring of the dynamic state of the grid assumes considerable significance, the time interval of such large magnitude poses constraints and hence monitoring and control of large and widely spread grid requires new technology which provides wide area time synchronized and time stamped measurement known as Synchrophasors. Deployment of such technology in India has also been envisaged in the Government of India report "Working Group on Power for 11th Plan" as well as in National Electricity Policy.[1]

Further the existing SCADA/EMS technology has the capability to provide only steady state view of the power grid whereas the synchrophasors measurements over wide-area facilitate dynamic real time visualization of the power system and these measurements 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 behaviour of the power system under different conditions and with this better utilization of the power system can be achieved without compromise on the reliability front.

Under the pilot project implemented by Northern Regional Load t in the Northern India on Synchrophasors measurement initially four PMUs have been deployed and more PMU locations are envisaged to be be added in the subsequent phases. Being the first Project of its kind, some challenges and concerns were faced and some lessons were learnt during implementation of the project. In the subsequent paragraphs all such concern and challenges and the leassons learnt during implementation of the project have been discussed.

2. Synchrophasors Technology

Synchrophasors are the phasor measurements taken synchronously at same instant of time. A phasor is a complex number that represents both the magnitude and phase angle of the electricity waves as shown in figure 1.

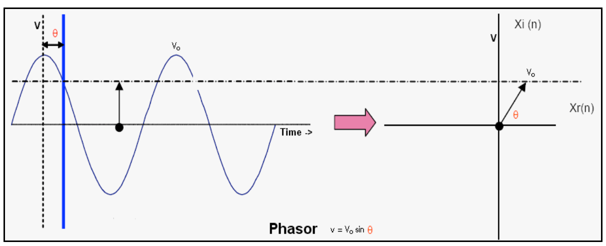

Fig. 1 - Phasor represents magnitude and phase angle at any given instant of sine wave of voltage or current.[2]

Synchrophasor measurements can be taken precisely and time synchronously by the devices called phasor measurement units (PMUs) which are synchronized with the help of GPS. These measurements are taken at high speed typically 25 or 50 observations per second. Each measurement is time-stamped according to a common time reference provided by GPS. 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 the grid state, and can be used to trigger corrective actions to maintain reliability.

A typical synchrophasors project, also known as Wide Area Measurement System (WAMS), 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 PDC (Phasor Data Concentrator) collects time-stamped measurements from connected PMUs, adjusts for the differing transmission latency times, accounts for timing and/or transmission errors and integrates all valid reporting PMU measurements into a single composite data packet with single time-stamp [3]. PDC passes these data packets to visualization and other applications software. Additionally the data is also sent to a data historian for storage and post analysis purpose. 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 according to a common time reference typically provided by the GPS installed at PMU locations. GPS also provides time synchronization among different PMUs.

3. Synchrophasors Pilot Project of Northern, India

The synchrophasors pilot project implemented in Northern India is consists of PMUs along with GPSs installed at four locations of the northern grid strategically chosen after a study of the Northern grid network with the aim of covering wide area of the Northern grid. A Phasor Data Concentrator located at Northern Regional Load Dispatch Center (NRLDC), New Delhi collects the information from all four PMUs on fibre optic communication channels. An operator console displays the data in real time through a visualization software and a data historian collects the data for storage and has the capability of exporting the data through a query based language. Data from historian can be made available to other systems on network through ODBC (Open Database Connectivity) in a spreadsheet for further analysis. The PDC has also been provided with an OPC server (Object Linking and Embedding for Process Control) in order to transfer real time phasor data to existing SCADA system. Architecture of the pilot project has been shown in Fig 2.

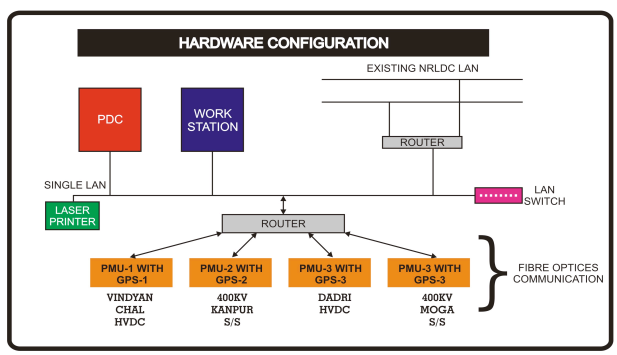

Fig 2 - Pilot project architecture

The PMUs under this project are located at Vindhychal HVDC, 400 KV s/s Kanpur, Dadri HVDC and 400KV s/s Moga. The work of addition of four more PMUs is in progressand these are being planned to be located at 400KV s/s in Kishenpur, 400KV s/s Hissar, 400KV s/s Bassi and 400KV s/s Agra. Each location has 1 PMU unit and 1 GPS unit installed in a panel along with a interface converter for converting Ethernet communication interface to G.703 interface.

The salient features of the system are as follows:

- Each PMU has one 3-phase voltage input, one 3-phase current input.
- PMUs are Level-I compliant of IEEE C37.118.
- GPS at PMU location has accuracy of 1 micro second or better
- Communication between PMUs at remote locations and PDC at central location follows IEEE C37.118 protocol.
- Reporting rate of data from PMUs to PDC is 25 observations per second.
- Phasor Data Concentrator is capable of providing data output in IEEE C37.118 as well as in OPC protocol.
- Data historian provide ODBC connectivity for making available historical data to Excel sheet and to Visual Basic program over the network.
- Operator console has visualization software for display of real time data as well as historical data in tabular form and trend graph form.
- Data from project has also been made available to existing SCADA system.

4. Commissioning of the Project

The project was conceived in the month June 2009 and was commissioned in the month of May 2010. Hence from concept to commissioning, the project took less than a year. and all activities related to the project viz. preparation and finalization of technical requirements, vetting of technical specifications by CEA, regulator's approval for funds, tendering and award of contract and installation and commissioning etc. were completed in this time span of 11 months.

5. Challenges and Trade-offs

5.1 Scale of Project

Biggest challenge, while planning this project, was that whether we should implement a full fledged project or first we should go for a pilot project and then scale it up to a full project. It is evidently known that Synchrophasors technology is still evolving worldwide and synchrophasors data is quite different from the data being received in existing SCADA system. While enumerating the major differences between the two, it can be seen that the first major difference is that synchrophasors data is acquired at high speed typically 50 samples per second while data in SCADA is acquired once in 4 to 10 second. Secondly the SCADA system measurements are done for the RMS value of the measurends like voltage and current on a span of 200 to 500 cycles while in synchrophasors measurements will be done many times within a cycle along with phasor angle. At present the synchronized phasor measurements are envisaged to be used for power system model validation, post event analysis, real-time display, and other similar activists [4], however the real time application of this data is still in R&D stage. Therefore assuming that to start with, the application would be mainly to acquire the data and mainly to do real time display and event analysis, we decided to go for a project on pilot level, initially with fewer PMUs and later on add more PMUs. We may go for involved application package only after we gain the initial experience on real system..

5.2 Type of Architecture

Synchrophasors projects implemented in the world elsewhere in general have two types of architectures, one is centralized and the other is decentralized. In decentralized architecture two or more levels of data concentrators are provided. Locations having more nos of PMUs have additional PDC as sub-station and called as sub station PDC level. Substation PDC reports to main PDC at top level. This type of architecture has its own distinct advantages like in case of communication failure data is not lost and stored locally and updated to main PDC after restoration of communication. However, this architecture is more suitable in the case where number of PMUs are large at one location. In our pilot project since it was envisaged with one PMU at each location centralized architecture is found more suitable. In this case, all PMUs report directly to main PDC . Trade-off was made in case of communication failure data will not be available. However, this can be overcome by using reliable and dedicated communication channels.

5.3 Selection of PMU Locations

Choosing locations of PMUs was also a challenge as only four locations were to be provided for covering widest area of the Northern grid. Considering that it is a pilot project involving only few locations, selection of the locations was been done on a heuristic approach. Criteria for selection of PMU locations followed:

- 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 PMU locations have been picked from the different groups considering the broad criteria mentioned above [5]. Locations and its significance in the Northern grid is shown in Table 1.

TABLE I

PMU LOCATIONS AND THEIR SIGNIFICANCE IN NORTHERN GRID

SN	LOCATION	Significance
1	HVDC Vindhyachal back to back station	A major thermal generation complex.
2	400 KV sub-station Kanpur.	A transmission system pooling station.
3	HVDC Dadri Terminal	A load center.
4	400 KV sub-station Moga.	A hydro generation pooling station.

5.4 Standard and compliance

IEEE C37.118 is the standard for synchrophasors for power system. This standard defines synchronized phasor measurements used in power system applications. It provides a method to quantify the measurement, tests to be sure the measurement conforms to the definition, error limits for the test. It also defines the communication protocol, including message formats for communicating this data in real-time system [6].

In order to ensure the interoperability of PMUs and PDC deployed in the project with PDCs of other manufacturers essential for future expansion of the project, it was decided to follow the IEEE C37.118 standard.

IEEE C37.118 provides accuracy measurement of the PMUs by TVE (Total Vector Error) which should be limited to 1%. TVE is the magnitude of the vector difference between the theoretical phasor and the phasor estimate given by the measuring device, expressed in fraction of the magnitude of the theoretical phasor [7]. Calculation of TVE as given in the standard is shown below:-

$$TVE = \sqrt{\frac{(X_r(n) - X_r)^2 + (X_i(n) - X_i)^2}{X_r^2 - X_i^2}}$$

Where $X_r(n)$ and $X_i(n)$ are the measured values, given by the measuring device, and X_r and X_i are the theoretical values of input signal at the instant of time of measurement, determined from Equation $X=X_r - jX_i$ and known conditions of X_m, ω, and ϕ.

In order to have conformity with IEEE C37.118 requirements, as per standard, phasor measurement should have the synchrophasors definition within one of two accuracy classes in addition to conforming to the communication protocol for reporting measurements. A PMU may be compliant either level-0 class or level-1 class. For the project, level-1 compliance was chosen because it provides to maintain TVE within 1% for signal frequency variation of ±5 Hz from nominal frequency.

5.5 Communication and bandwidth requirement

The standard does not impose any restriction on the communication media itself. Basically a Configuration frame, Data frame, Header frame and a Command frame are specified. These have a particular structure and data type associated with them. Configuration frame, Data frame, and Command frame are binary type and Header frame is of ASCII type. The Data frame is the most frequently transmitted message based on the PMU sample rate, and the typical size is of the order of few hundreds of bytes. The variable size in the data frame is the number of phasors, analog values and digital signals transmitted, depending on the PMU capability. For 12 phasor channel with reporting rate of 50 frames per second the required bandwidth is 56.7 kbps [8]. PMUs deployed in the project have the capability of 3 voltage phasors, 3 current phasors and 2 analog values (frequency and df/dt). Hence, communication channel of 64 kbps bandwidth have been used for the project.

Since, availability of communication channels was also the criteria while selecting locations of PMUs, we could save time and efforts in provisioning the communication channels for the project as communication channels have been provisioned from the existing fibre optic infrastructure.

A dedicated IP wide area network was planned within PMU locations and PDC location, we found no difficulty in assigning the IP address to various devices, as being a private WAN, IP address were assigned from private IP address block. However, on the front of communication signal interfacing, issue arises, as existing infrastructure was having G.703 signal interface for its 64kbps channel. For the project Ethernet interfaces were required otherwise we would have to provision 2 Mbps E1 links as routers were provided with G.703 interface for E1 channels only. This challenge was resolved by providing interface converters for converting the signals from G.703 to Ethernet at all PMU location as well as at PDC location.

5.7 Setting up of communication with PMU.

Distance between the PMU panel and communication multiplexer at some PMU locations was one of the major challenges faced during execution of the project. PMU panel was to be installed in control room in order to get CT and PT connections from the adjacent control panels while communication terminal were available in communication room. At some locations, distance (cable route) between control room and communication room was such that using a copper connection was not feasible due to distance and electrical interference. At such sites, fibre optic cable along with media converters were provided to resolve these issues.

5.8 Data Storage and Retrieval

As the whole project was conceived to gain first hand experience of synchrophasors measurement and technology, easy availability of real-time data as well as historical data to other computers is of much important. Hence a data historian suitable for time series data was provided. In order to reduce the time taken for retrieval of historical data, on line storage of the data on a dedicated server with sufficient storage capacity so as to accommodate data for 12 months for 20 PMUs was provided. This capacity is further expandable by adding hard disk in spare bays available in the server. PDC has been provided with a OPC (OLE for Process Control) server for providing real time data to external devices.

6. Concerns and Lessons Learnt

During the implementation of the project we addressed many concerns and gained valuable knowledge which shall be very helpful in future project and will help to avoid implementations issues and delays. We felt that it was very important for all the participants like designers, implementers, vendor to work closely and coherently in such type project in order to avoid interfacing issue etc.

As mentioned earlier, for compatibility of communication signal interface, interface converters have to be deployed consuming extra time and efforts. A detailed analysis and planning of communications system availability as well as requirements may further optimize time and efforts required.

As an IP WAN was being used for communication from PMUs to PDC, the establishment of communication between PMU and PDC could be very easily verified by using ping utility. However, verification of communication of IEEE C37.118 data was a concern. PMU connection tester, an open source utility developed by Tennessee Valley Authority came to our rescue. We could test the communication and verify the protocol data and packets with the help of this software with ease.

Security was a major concern during implementation of the project. But the avoidance of shared or public communication media and use of dedicated communication channel and that's too from the self owned and self managed infrastructure could address this concern.

Local Area Network of PDC, data historian server and operator console was required to connect to SCADA LAN for transfer of real-time data to SCADA LAN in order to make real time synchrophasors data available to SCADA users. To prevent transmission of any security threats from/to SCADA and PDC LAN, a router was used for connecting SCADA LAN with PDC LAN. But the problem of malfunctioning of multiple gateways on single network controller card (NIC) was making the availability of data to SCADA unreliable. Alternatively, we used second NIC available in server for connecting SCADA LAN. This solution was found reliable and easy to implement.

For the purpose of analysis of events etc, data from historian server was required to be retrieve to computers connected to office LANs. The possible solution was to use pen drives and query and copy the data from historian server to office computers. However, this may pose the risk of viruses infection from office computer to data historian server. Moreover, this process will be time consuming also. To resolve this we used a spare computer having two network cards one card connected to PDC LAN and other card connected to office LAN. This solution proved very useful later on.

7. Conclusion

The project was implemented with a time period of less than one year from concept to commissioning. The outcome of project found very useful especially in understanding hidden secretes of the power system behaviour.

With the advancements in communication and information technology and the ever increasingly need of wide-area visibility for power grids, synchrophasors initiatives are being taken in India at various places. The challenge faced, trade-off made and lessons learnt during course of implementation of synchrophasors project in Northern India would benefit the power system fraternity in forthcoimg synchrophasors projects. The experience gained during initial operation, being Indian specific experience, can well be leveraged to other synchrophasors initiatives under way. The project would be of great help to the academician and researches as well as technology planner in Indian power sector. The availability of actual data will also contribute in development of WAMS and its application in India.

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