Novel usage of Synchrophasors for system improvement: An experience in Northern Grid of India

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Abstract—The advent of new technologies like Synchrophasors have given the operator an extra edge. Apart from usage for post disturbance analysis, the synchrophasor based inputs are also becoming an integral part of applications for enhancing the real-time visibility of power system as well. In India, since its inception, with very few Phasor Measurement Units (PMU) in place, the synchrophasor technology has been used extensively at the Regional and National Load Despatch Centres. Through synchrophasor inputs from various locations, the power system operator is observing the voltage, current, frequency, phase angle thereby deducing the system health. The early detection of problem with single phase auto-reclosing during single phase to ground faults in transmission system, Capacitive Voltage Transformer (CVT) health and visualization of black start exercises at control centers have been some of the challenges in power system operation. This paper discusses the new effective usage of synchrophasors and wide area monitoring at Northern Regional control centre in overcoming these challenges for power system improvements.

Keywords—Auto reclosing, Big Data, Capacitive Voltage Transformer (CVT) error, Electrical fault detection, Phasor Measurement Units, Reactive Power Control, Synchrophasors, Voltage fluctuations, Voltage measurement

I. INTRODUCTION

The Indian Power system is demarcated into five regions viz. Northern, Eastern, Western, Southern and North-Eastern regions respectively synchronously connected with each other. The Northern Region includes Punjab, Haryana, Rajasthan, Delhi, Uttar Pradesh, Uttarakhand, Himachal Pradesh, Jammu & Kashmir, Chandigarh. The Northern Regional Load Despatch Centre (NRLDC) looks after the operations of Inter-State Transmission Network of aforementioned nine states/Union Territories.

The first synchrophasor pilot project in Northern Region was commissioned in the year 2010 wherein 4 number of PMUs were installed at strategically chosen locations [1]. Since then, the synchrophasors assumed a key role, both for providing real-time monitoring through enhanced visualization as well as for post-event analysis measures by adding a new dimension through its fast, accurate and synchronized observability. The architecture of Synchrophasors at Regional and National level is given in reference [2, 3]. In the region, synchrophasor based data is being used in fault analysis, oscillation analysis, multiple tripping event analysis, Frequency Response Characteristics calculations, analyzing weather related contingencies, Rate of Change of Frequency (RoCoF) based tripping event analysis etc. [2, 3, 4]. Apart from these, the new usages of synchrophasors are also being continuously explored. This has broaden the scope of usage and utility of the synchrophasors.

Based on the beneficial experience of synchrophasors more than 1600 PMUs are further being added in the Indian Power System under the Unified Real Time Dynamic State Measurements (URTDSM) scheme of which more than 450 PMUs are earmarked for Northern Region itself [5]. This wide area monitoring system is certainly a system insight tool at operator’s disposal. The scheme also has development of few analytic applications in its scope as well. Apart from development of these analytic tools, synchrophasors are being used in number of different ways for improvement of system.

The large infrastructure of transmission system is prone to faults during varied climatic conditions. Therefore, a lot of faults, protection operations are observed at the regional control centre. Since, most of the faults are single line to ground faults, one of the important observation would be the single phase auto-reclosing of line experiencing fault. Further, monitoring of any abnormal switching of transmission element, abnormal value of parameters is captured by the operator and is used as an early warning signal for corrective actions.

The synchronization of subsystems during black start exercise requires matching of frequency, voltage, phase angle, phase sequence and same is ensured through synchronization trolley at substation level at the point of synchronization. Therefore, the same was available at local level only. However, the synchrophasors being time stamped and very granular data, replicating the synchronization trolley at control centre could be attempted for assistance during synchronization, charging process. The paper presents a few novel usages of synchrophasors at Northern Regional control centre of India to take care of above aspects.

II. CASES OF NOVEL USAGE OF SYNCHROPHASORS IN NORTHERN REGION OF INDIA

A. Finding anomaly in single phase auto-reclosing timing

The high voltage transmission lines in the Northern Grid are having single phase auto-reclosing. The dead time for the same is set at 1000ms for most of the lines as per the
protection philosophy [6]. Further, the standard for fault clearing time for any fault in 400kV and above voltage level system is 100ms [7]. At control centre, during a single phase to earth fault in a transmission line, the attributes like faulted phase, fault clearing time, auto-reclosing dead time is captured with the help of synchrophasor data. Fig. 1 depicts a typical example of single phase fault analyzed from synchrophasor data. Any deviation in auto-reclosing dead time observed from PMUs is reported to concerned entity for correction.

During a single phase fault, the actual details viz. Disturbance Recorder (DR) output, event logs of the stations at the two ends may not be the first hand information available at the control centre. The operator uses the synchrophasor data for estimating the fault clearing time. However, for a single non-temporary phase fault, a minor difference in auto-reclosing time at the two ends may appear with the signature of delayed fault clearance at the time of auto-reclosing of faulted phase. For instance, as per the R(red), Y(yellow), B(blue) phase convention, a Y-phase fault occurred in a transmission line A-B. Fig. 2 shows the bus voltage magnitude of a PMU at one end, End-A of the line. Similarly Fig. 3 shows the bus voltage magnitude of other end, End-B of the line. From Fig. 2 and Fig. 3, a signature of delayed fault clearance is observed at the time of auto-reclosing of line. Hence, the operator may tend to register a case of violation of regulation on account of delayed fault clearance observed.

However, as shown in Fig. 4, from close observation of both end PMU data plots, it could be seen that it is not a case of delayed fault clearance but a signature arising from different dead time of auto-reclosing at both ends. Hence, through this new usage of synchrophasors, the difference in auto-reclosing time at two ends of a line can be found out. For a higher difference in auto-reclosing time at two ends, signature of two successive faults may appear at the time of auto-reclosing of line. This signature is being utilized at the control centre to give feedback to the utility based on such cases of different dead time at two ends observed by the operator.

**B. Voltage calibration using synchrophasors**

The three phase voltages is an important information for system operators to monitor and analyze the grid. In Northern Region alone, around 500 three phase voltage points or nodes are available through more than 250 PMUs installed. An algorithm is being used to check the imbalance in the three phase voltage magnitude of all the points/CVTs available through PMUs. The following voltage magnitude imbalance formula is used:

\[ X = |V_R - \text{Average of } (V_R, V_Y, V_B)| + |V_Y - \text{Average of } (V_R, V_Y, V_B)| + |V_B - \text{Average of } (V_R, V_Y, V_B)| \]

where, 
\( V_R, V_Y, V_B \) are three phase voltage magnitudes of a node.
X is voltage imbalance factor.

The abnormal value of X for a particular node indicates the imbalance in voltage magnitude at that node. Thus, in place of going for monitoring each node separately for an imbalance in voltage magnitude, a collective monitoring using the voltage imbalance factor, X is carried out. Fig. 5 shows the algorithm used in the method.

For a particular time stamp, the typical value of X for available PMU voltage nodes in Northern Region came out to be less than 5kV. However, for a handful of nodes, X was more than 12kV. Fig. 6 shows the value of X for few of the nodes.

The exercise yielded a total of 15 points wherein the problem in measurement was suspected due to Voltage transformer (CVT/VT) or other issues. The respective utilities having this suspected voltage imbalance were advised to check the CVT/VT for any error. Fig. 7 indicates the voltage magnitude imbalance found at one such station’s line voltage as observed from synchrophasor data. Fig. 8 shows the DR output of that location which also indicates lesser R-phase voltage in normal operation. On the basis of feedback given to the utility of the station, the utility replaced the CVT at the measurement location. Fig. 9 shows the voltage magnitude profile of the aforesaid point after the replacement of line CVT based on Synchrophasor data whereas Fig. 10 shows the DR output of the same. Thus, with the use of synchrophasors, calibration of CVT/VT of such big data was achieved.
C. Voltage calibration using synchrophasors

Mock blackstart exercises of hydro and gas power plants are carried out in the Northern Region by creating a sub system having a generator or group of generators feeding a load. The subsystem runs at a frequency different from that of the rest of the grid. On completion of the exercise, the subsystem is synchronized with the grid [8]. These exercises are part of routine preparation for system restoration in case of blackout or brownout [9]. The exercises are witnessed by personnel from power plant, other involved stations as well as at control centres. At control centre, it was a practice during the exercise to monitor the parameters through Supervisory Control And Data Acquisition (SCADA) data. However, with the introduction of large number of PMUs, the exercises are also being monitored using synchrophasor data.

A mock blackstart exercise of one Hydro station feeding a small load carried out in Northern Region. The exercise was witnessed through available synchrophasor data. During the synchronization of the subsystem, the voltage and frequency of island was being matched to that of the grid at the point of synchronization. Based on the data available from PMUs, the remote end line voltage was being matched with bus voltage of synchronization point station-D. Further, the island frequency was being matched with grid frequency. Fig. 11 and Fig. 12 depicts the synchronization process.

D. Persistent fluctuations in voltage

A major usage of synchrophasors in Northern Region is finding shunt faults in the power system. A single phase fault could be identified by observing a voltage dip in voltage magnitude of faulted phase voltage or a phase to phase to ground fault could be identified by around same amount of voltage dip in faulted phases. However, what could be the reason if voltage magnitude fluctuates? An incident of fluctuations in voltage occurred. The Y-phase voltage of nearby PMU of affected station was showing large fluctuations with a time period of around 4 seconds. The fluctuations lasted for 4 minutes. Fig. 13 depicts the behavior of bus voltage of affected station-C. It could be seen that negative spikes of around 3kV in Y-phase voltage occurred at every 4 seconds.
A few peculiarities observed in the incident are:

- Initial rise in magnitude of all three phase voltages.
- Sustained fluctuations for 4 minutes.
- Time period of fluctuations being 4 seconds.
- Fluctuations dominant in only one phase i.e. Y-phase only.
- Around 1% dip in voltage magnitude of Y-phase at each fluctuation instant.

The following details received from the affected station:

- The substation was having one and a half bus scheme at 400kV voltage level. In one of the diameter, two 125MVAR bus reactors were present. However, both the reactors were to be replaced by 400kV circuits in future. An auto-reclosing lockout relay was inadvertently in service for both the reactors as a line protection for future lines.
- A DC earth fault rectification work was under progress. During checking, the DC supply extending to the trip coil-2 of bus reactors diameter got affected. As a result, both reactors tripped.
- The auto-reclosing lockout relay also miss operated which resulted in repeated closing of Y-phase of bus reactors. The phenomena continued for around 4 minutes. The station operator saw the phenomena and informed the testing team which then switched off the supply.

After the incident, the DC fault was identified and rectified and the auto-reclosing lock out relay was switched off till the commissioning of future lines. This signature based upon peculiarities observed in case of voltage magnitude fluctuation is noted. The operator sees and report for any similar kind of signature in the daily operation.

III. CONCLUSION

Since inception, the usage of synchrophasors is increasing day by day. In Northern Region of India, the above novel usage synchrophasors have further improved the situational awareness of the operator. The millisecond phenomena like auto-reclosing time difference, two different subsystem synchronization can be effectively addressed through usage of synchrophasors. On the other hand, the long duration changes like voltage magnitude imbalance, persistent voltage magnitude fluctuation can also be efficiently dealt with. Thus, these newer and newer usages of synchrophasors are great help to the system operators in improving the reliability and security of the power system.

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