

Application of Synchrophasors in Grid Event Analysis

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SUMMARY

Worldwide the Synchrophasor technology is being deployed for providing access to time-synchronized phasors at the control centre. Synchrophasors have enhanced wide-area visualization and situational awareness of power system behaviour under steady state as well in transient/dynamic conditions [1, 2, 3]. A pilot project has been taken up in India to explore the application of synchrophasor. This paper illustrates the utility of synchrophasors in post-dispatch analysis of grid operation; detection of nature of fault and fault clearance time in the EHV transmission system; visualization of 1-ph auto-reclosure in EHV transmission lines; and validation of sub-station Event log and Disturbance records. The authors suggest that the synchrophasors should supplement the existing information (through SCADA/EMS) available at the control centres to address the challenges faced in forensic analysis of grid events.

KEYWORDS

Grid event analysis, Synchrophasor, Protection, Disturbance Record, Event Log, Control Centre

INTRODUCTION

The Indian grid is demarcated into five regional grids. Four out of these five regional grids are synchronously connected with each other. Fourteen (14) Phasor Measurement Units (PMUs) have been commissioned all over India as on 31st May 2012. In the Northern Region, the PMUs have been placed at nine 400 kV substations viz. Vindhyachal (HVDC back-to-back station), Kanpur (with SVC), Dadri (HVDC inverter terminal), Moga, Kishenpur, Agra, Bassi, Hisar and Karcham Wangtoo. In Western Region PMUs have been placed at two 400 kV substations viz. Raipur and Bhadravati. In Southern Region, they have been placed at three 400 kV substations viz. Salem, Hyderabad and Bengaluru. The three Phasor Data Concentrators (PDC) have been installed at the respective Regional Load Despatch Centres (RLDCs) located in New Delhi, Mumbai and Bengaluru respectively. The data from the three PDCs at the regional level have further been integrated at the National Load Despatch Centre (NLDC), New Delhi to obtain a countrywide picture. Additional PMUs/PDCs are being placed progressively. [4,5,6,7]

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The availability of synchrophasor data at every 40 millisecond interval from few locations has made it possible to visualize the magnitude and angle of all the three voltage/current phasor; sequence components of voltage/current phasors; frequency and frequency difference, rate of change of frequency and angular separation between pair of nodes in real-time at the Load Despatch Centre. The data is being also used in post-dispatch analysis. The five case studies illustrate few of the important applications of synchrophasors in India.

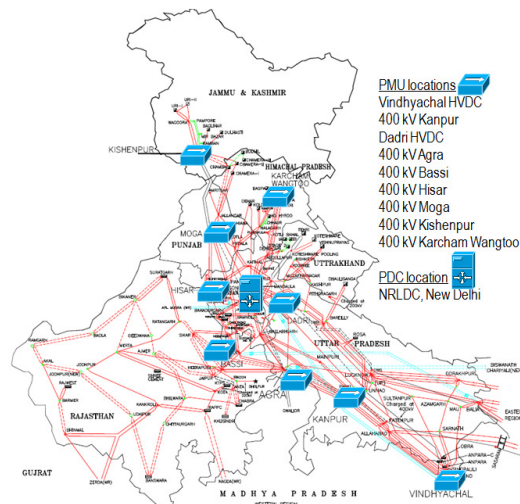


Figure 1: Location of PMUs and PDC in Northern Region in India

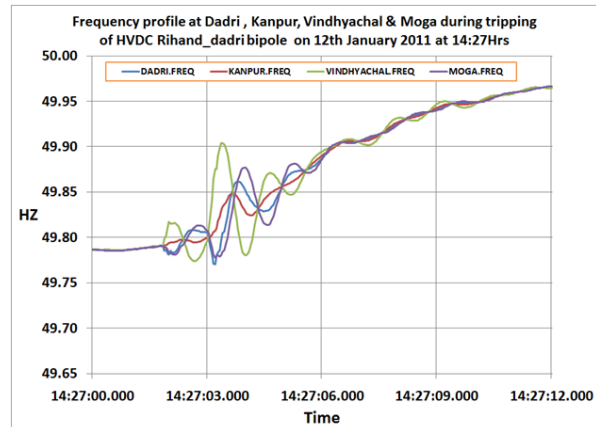


Figure 2: Visualization of frequency from various locations within the synchronous system in a perturbed system

CASE STUDY-1: DETECTION OF OSCILLATIONS IN THE POWER SYSTEM

1000 MW Tehri Hydro Power Station (4x250 MW) located (in Uttarakhand) at a remote end of the Northern Grid. Power is evacuated through two 765kV Tehri-Meerut line (charged at 400 kV) having quad bersimis conductor. The connectivity diagram of Tehri Hydro generating station in Northern region is given in Figure-3. The power stations had reported problems in generating at full load under outage of one of the two evacuating circuits. Therefore an exercise was carried out on 3rd Feb 2011 from 11.25 hrs to 11.35 hrs to investigate the matter and validate the loadability of the transmission system under N-1 contingency.

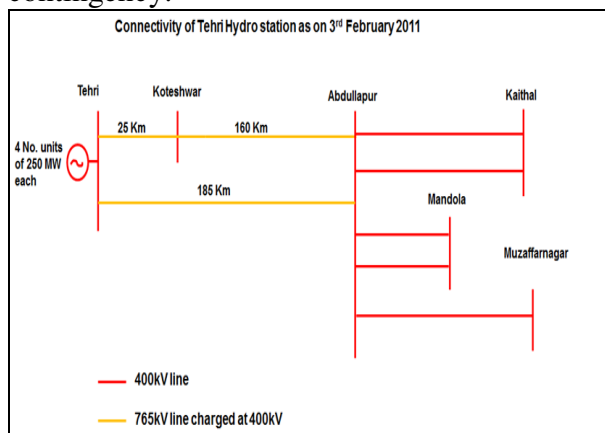


Figure 3: Connectivity of Tehri HPS with the grid

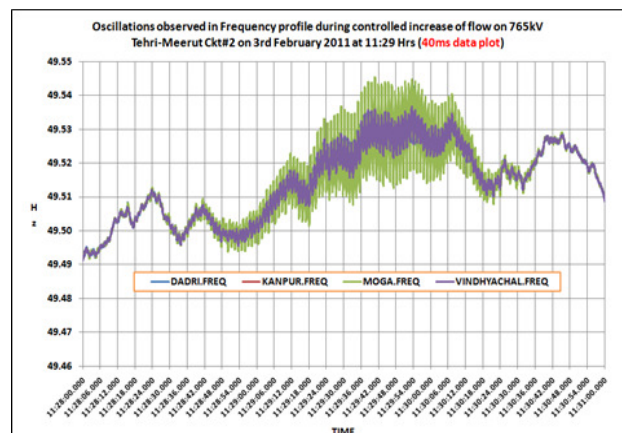


Figure 4: Oscillations when Tehri generation > 700 MW with only one out of two evacuating circuits

With the help of synchrophasor data low frequency oscillations (0.833 Hz) were observed (Refer figure 4) when the generation at the station was increased beyond 700 MW. Further,

analysis and off line studies revealed ill-tuned PSS at the generating station. The Power System Stabilizers (PSS) at Tehri were tuned and series compensation was also commissioned on the evacuating circuits from Tehri. The problem was thus resolved satisfactorily.

CASE STUDY-2: ANALYSIS OF A SYSTEM PROTECTION SCHEME

As a part of the on-going capacity addition initiative in India, large generating stations and associated transmission system are being planned and executed by private and public sector enterprises. In one such large hydro project of 1000 MW (4x250 MW) capacity had been envisaged at Karcham Wangtoo (in Himachal Pradesh) along with 400 kV double circuit Quad Moose lines to Abdullapur (in Haryana). Two units of this station were ready for commissioning in before the associated transmission lines were ready. In order to facilitate utilization of the available capacity from this station, it was decided to evacuate the generation from new units through the transmission system already existing (4 circuits of Triple Snowbird) for the Nathpa Jhakri (6 x 250 MW) and Baspa (3x100 MW) hydro generation complex in the vicinity. The connectivity diagram may be seen in figure-5. A System Protection Scheme was also implemented to secure the system for N-1 contingency. The SPS was supposed to trip the new generating units at Karcham Wangtoo in case the loading on any of the evacuating lines from the complex exceeded 800 MVA or if one or more out of the existing four circuits tripped [8].

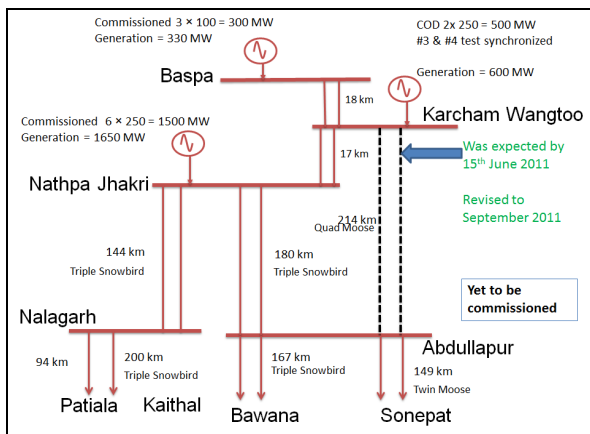


Figure 5: Connectivity diagram of Jhakri-Baspa-Karcham complex

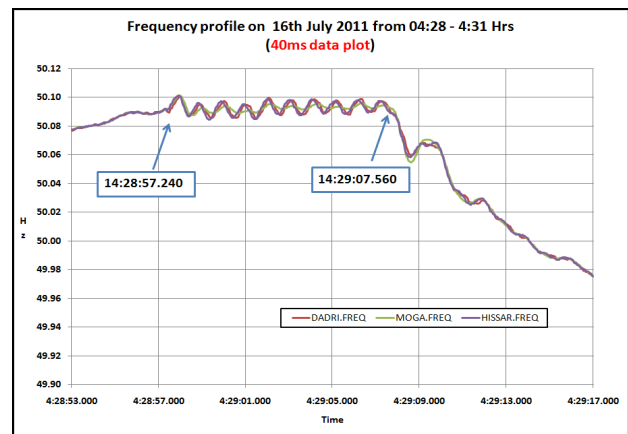


Figure 6: Oscillations for 10 seconds observed in synchrophasor data

On 16th July 2011 at 04:28 hrs when the antecedent generation in the Jhakri-Baspa-Karcham complex was around 2400 MW, one of four outgoing lines from Jhakri complex tripped. In the post-dispatch analysis, it was observed that consequent to the contingency, system-wide oscillations were recorded in the synchrophasors data (Refer figure-6). The oscillations subsided after 10 seconds (Refer figure-6) when the 2x250 MW units at Karcham Wangtoo tripped.

The time of occurrence of the contingency and the operating time of breakers of transmission line and Units were examined (Refer table-1 & 2). It was inferred from table-1 that circuit breakers of 400kV Jhakri-Abdullapur line-2 tripped at 4:28:57.313 hrs which matched with the SCADA SOE and PMU data. It was inferred from table-2 that by 4:29:07.990, both units at Karcham Wangtoo HPS had tripped. This time matched with the event time as inferred from PMU data i.e., 4:29:07.800. Thus it was concluded that the total SPS operating time was 10.677 seconds, which was significantly higher than the envisaged SPS operation time of few hundred milliseconds. Thus it was concluded that the oscillations had sustained for 10

seconds because the SPS operation got delayed by around 10 seconds. The delay in operation time of the existing SPS was addressed by suitable modifications in hardware and software.

Table 1: Tripping time details of 400 kV Jhakri-Abdullapur line-2

Event at Jhakri Hydro Station	Jhakri Hydro Station Event log	Control Centre SCADA Sequence of Events (SOE)	As inferred from Synchrophasors
Time of operation of Over voltage protection in 400kV Jhakri-Abdullapur line-2	04:28:57.296	Not wired	4:28:57.240
Time of tripping of breaker of 400kV Jhakri-Abdullapur-2	04:28:57.313	04:28:57.226	

Table 2: Tripping time details received from Karcham Wangtoo HPS

Event at Karcham Hydro Station	Karcham Wangtoo Station Event Log	Control Centre SCADA SOE	As inferred from Synchrophasors
Time of receipt of SPS signal at Karcham Hydro station	04:29:07.217	Not wired at the time of the event	---
Tripping of unit -2 at Karcham	04:29:07.898		04:29:07.800
Tripping of unit -1 at Karcham	04:29:07.990		04:29:07.800

CASE STUDY-3: FAULT ANALYSIS AT THE CONTROL CENTRE

Analysis of the nature of fault and the fault clearance time is conventionally done with the help of relay flags, disturbance records and event logs available from the concerned substations. This information may not always be available at the control centre due to various issues regarding data sharing between utilities or may not be available at the time of analysis.

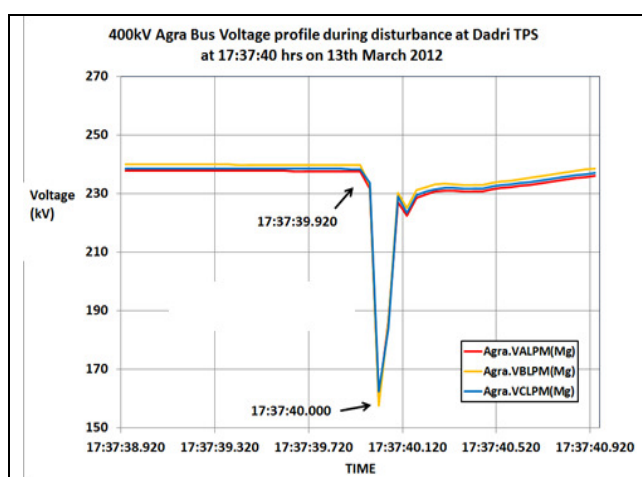


Figure 7: Three phase fault seen through synchrophasors

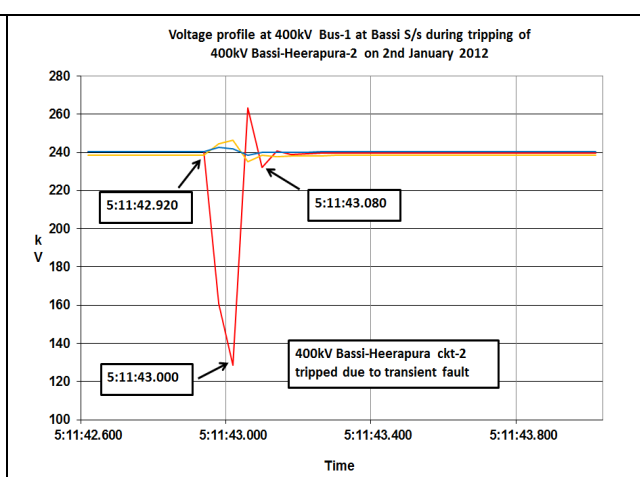
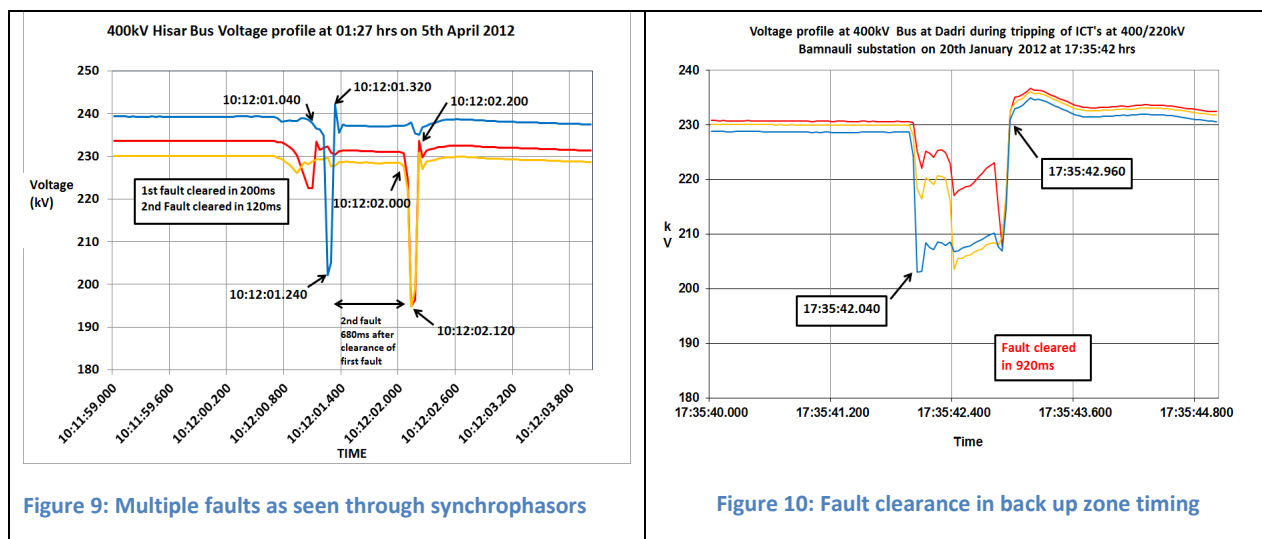


Figure 8: Single phase fault seen through synchrophasors



The SCADA/EMS with its inherent latency, skewedness are insufficient to provide conclusive evidence with regards to the nature of fault (single phase/multi-phase, balanced/unbalanced) and the performance of the protective gear in respect of fault clearance time. The SCADA data does not specify the phase. Thus the control centre engineers are often constrained in analysis of faults occurring in the system unless the information from the field stations are available in time.

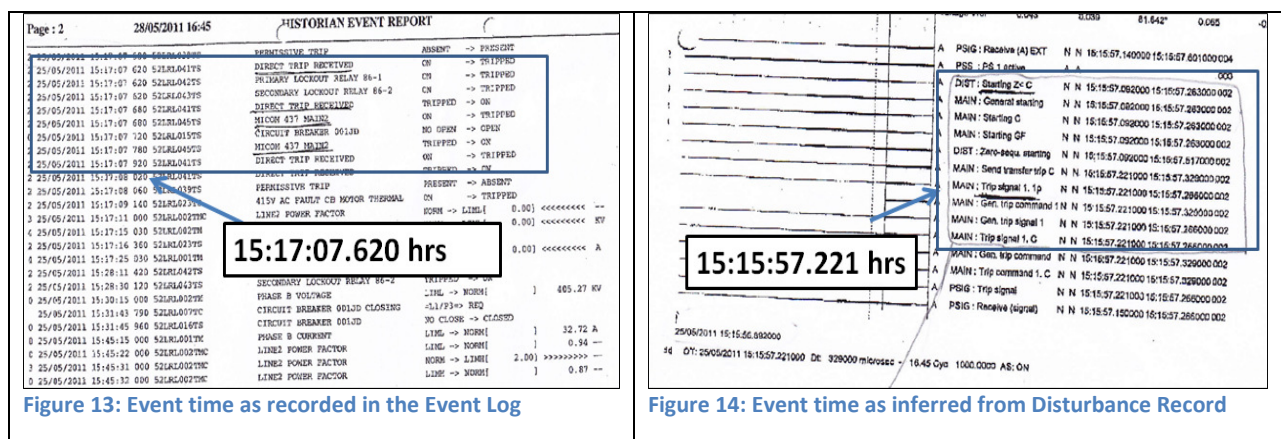
Table 3: Few typical Grid events that were analyzed with the help of synchrophasors

Sl. No.	Event Date	Event Time (hrs)	Event Details	Was the Disturbance Record / Event Log from the substation available at the Control Centre
1	2-Jan-12	4:00 to 6:00	Multiple auto-reclosure of an important tie line	Yes
2	12-Feb-12	10:20	Multiple tripping at an EHV substation due to absence of bus bar protection	No
3	14-Jan-12	05:39	Complete loss of an EHV substation due to bus fault and protection misoperation	Yes
4	20-Jan-12	17:35	Multiple tripping at a EHV substation due to failure of primary protection	No
5	13-Mar-12	17:37	Complete loss of a large generation complex at load centre	No
6	2-Apr-12	1:26	Load throw off due to tripping of EHV Inter-Connecting Transformers	Yes
7	19-Apr-12	3:29	Generation loss at a large pit head generation complex	No
8	26-May-12	8:32	Generation and Load loss due to multiple forced outage	No

CASE STUDY-4: VISUALIZATION OF AUTO-RECLOSURE IN EHV LINES

Figure 11: 1-ph auto reclosure seen in synchrophasors data

It is essential for the Disturbance Recorders to be GPS synchronized. During the analysis of an event that occurred on 25-May-2011, mismatch was observed between the timing of the event as seen in the Disturbance Records/Event log received from the substation and those seen in synchrophasors plots.



The time of occurrence of fault as per the EL was 15:17:07.620 (Refer figure 13) while as per the DR it was 15:15:57:221 (Refer figure 14). Therefore station disturbance recorder and Event Log were compared with synchrophasor data available at the regional control centre. The time of fault as inferred from the synchrophasors data was 15:17:07.840 hrs (Refer Figure-12). Thus the need for time synchronization of the Disturbance recorder was established.

CONCLUSION

The paper has illustrated few applications of synchrophasors in Indian power system. Synchrophasors have particularly been very useful in post-dispatch event analysis. Thus it complements the existing information available in the form of disturbance records, event logs and SCADA/EMS. Customized applications of synchrophasors in the operation and well as planning domain need to be quickly developed for further exploitation of the technology. In the operational time domain, there is a need for developing customized applications to realize the potential of the technology particularly in view of its utility for large scale integration of renewable energy sources and reliable operation of the large synchronous pan India/SAARC grid.

ACKNOWLEDGEMENTS

The authors acknowledge the support and encouragement given by the management of Power Grid Corporation of India and Power System Operation Corporation Limited. The authors also acknowledge the valuable contribution of colleagues and other utility engineers for providing valuable insights and inputs.

DISCLAIMER

The views expressed in the paper are that of the authors and may or may not represent the views of the organizations to which they belong.

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