Experience of HVDC operation in Southern Region

A Study using PMU data

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***Abstract*—High Voltage Direct current (HVDC) systems are in use for long distance transmission for bulk power. Besides incurring lower transmission losses they are in use to connect two asynchronous systems, and help improve dynamic performance of interconnected system. This paper discusses the various operational experiences in Southern Region (SR) grid for ±500 kV, 2500 MW, Talcher-Kolar bipolar HVDC link using PMU data which are installed at various 400 kV buses. . The paper highlights the Voltage and Frequency Control performed using HVDC controls in real time operation, Protection aspects & various phenomenon specific to HVDC operation like pole blocking, commutation etc. This paper also briefs about the future scope in HVDC operation regarding improving dynamic performance.**

***Index Terms*—HVDC, PMU, Low frequency Oscillation (LFO), Pole tripping, Filter tripping**

I. INTRODUCTION

HVDC Transmission system first came into existence in India in the year 1989 between Sileru and Barsoor at a voltage level of 200 kV. Since then four (Rihand-Dadri, Talcher-Kolar, Balia-Bhiwadi, Mundra-Mahendragarh) bipole and seven back-to-back HVDC links have been commissioned and are in operation.

The 2500 MW, ± 500 kV Talcher-Kolar HVDC bipole transmission system is the largest bipole link in India which facilitates evacuation of power from NTPC Talcher to the Southern region. A schematic diagram of an HVDC bipole system is shown in Figure 1.

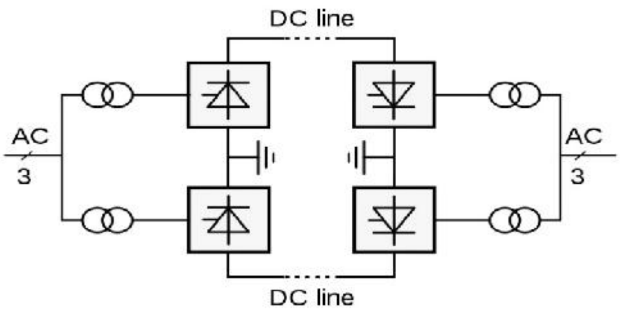

Figure 1: Schematic of HVDC bipole system

Inherent technical advantages associated with HVDC transmission have always encouraged planners to use HVDC along with AC. For instance due to unavailability of spinning reserve primary control (free governor mode of operation) etc., any generation loss or tie line tripping may result in sharp changes in frequency which may cause cascade tripping. Similarly for, HVDC blocking of a pole may cause severe operational issue which may jeopardize security of interconnected system. To overcome this Special Protection Schemes (SPS) has been implemented for fast load relief in SR region and generation reduction in ER region during contingency of tripping of single pole/bipole of the HVDC link [1].

Data acquisition in existing SCADA/ EMS systems through RTUs placed throughout the system. This information is captured at every 4-10seconds at respective control centers without time stamping. Phasor measurement units report the power system data at very high sampling rate (up to 50 samples/second) with synchronized time stamp.

In this paper we discuss the operational experience of the Talcher Kolar HVDC link through some selected cases using PMU data. The case studies help in highlighting the voltage and frequency control as well as the protection aspects regarding this line.

II. CASE STUDY I

On 22nd April 2012 at 14:30 hrs, Pole 1 and Pole 2 of the Talcher-Kolar HVDC line got tripped due to Commutation failure, which happened due to R-phase CT blast of 220kV Somanahalli-HSR layout at Somanahalli end. The 400/220kV Somanahalli ICT-1 and 2 Tripped on backup over current protection. The Power flow in the line came down as a result of the event from 1970 MW to 0 MW and frequency came down from 49.79 to 48.88 Hz. The flow on various HVDC lines is shown in Table. 1.

Table 1: Flow on HVDC lines prior and post event

Inter-Regional Flow In MW	Talcher-Kolar Pole-I	Talcher-Kolar Pole II	Gajuwaka HVDC	Chandrapur HVDC
Prior to event	985	985	251	866
Post event	0	0	251	862

The following steps were taken immediately after tripping of the pole- 1 & 2, in order to arrest further fall of frequency,

- The power import at HVDC Gajuwaka was increased from 250 MW to 600 MW and power import at HVDC Bhadrawati increased from 900MW to 1000 MW.
- SR constituents were advised to regulate generation/load.

The sequence of events that happened in course of the event has been shown in Figure 2 and Figure 3. Figure 2 shows the reactive power flow during the event. Due to the CT blast, the R-phase jumper short-circuited with Y phase. The 220 kV Busbar protection failed to operate and as a result of the persistent fault IDMT on HV side of the ICT operated. The data obtained is from the PMUs situated at Bangalore, Hyderabad and Salem.

On analyzing the events it can be seen that Pole 1 and 2 experienced 7 commutation failures. As per design of HVDC controls, the protection inherent to Pole control detects reduced short circuit level by repeated commutation failures. If a commutation failure is detected for the affected pole, a monitoring time (1 min.) is started and a counter is incremented. If the counter reaches a first limit (3) during this time period, the respective pole current limit is decreased to 75% (Stage 1). As soon as a second limit (6) of commutation failures is reached within the monitoring period, a further decrease to 50% is initiated (Stage 2). If after a delay (Pole 1: 200 ms, Pole 2: 400 ms) again a commutation failure is detected, the pole is finally tripped (Stage 3). As can be seen in the reactive power and positive sequence voltage plot, 7 spikes can be seen corresponding to the 7 commutation failures.

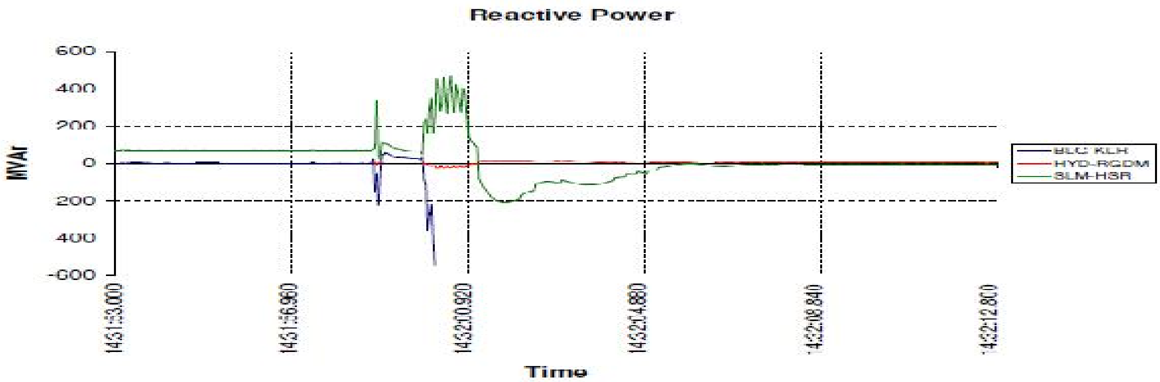

Figure 2: Reactive power flow on 22/03/2012

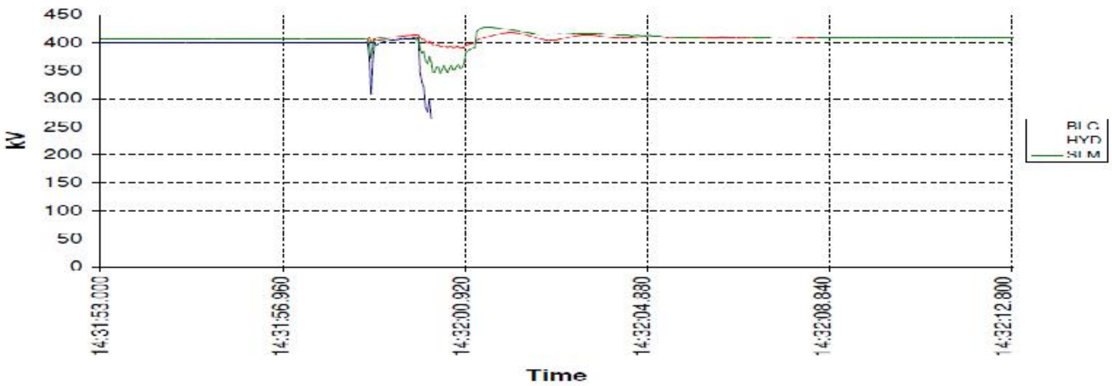

Figure 3: Positive Sequence Voltage on 22/03/2012

Immediately after the event, generation at Idukki increased by 150MW and at Sharavathi generation increased by 70 MW approximately on FGMO action. During the blocking of Bipole, SPS at Talcher acted and unit no. 6 tripped and generation of unit no. 4 and5 backed down by 150 MW each while the SPS at Kolar failed to act. HVDC Talcher-Kolar Pole-2 was de-blocked at 15:02 Hrs and Pole-1 was de-blocked at 15:08 Hrs on 22.04.2012.

III. CASE STUDY II

On 9th May 2013 at 04:11 hrs, Pole -1 of HVDC Talcher – Kolar link got tripped due to failure of CT in Bus 1A at Kolar. Power flow on the HVDC link was 1745 MW prior to the event. The current reduction characteristics of the HVDC line without changing over to metallic return is shown in Figure 4.

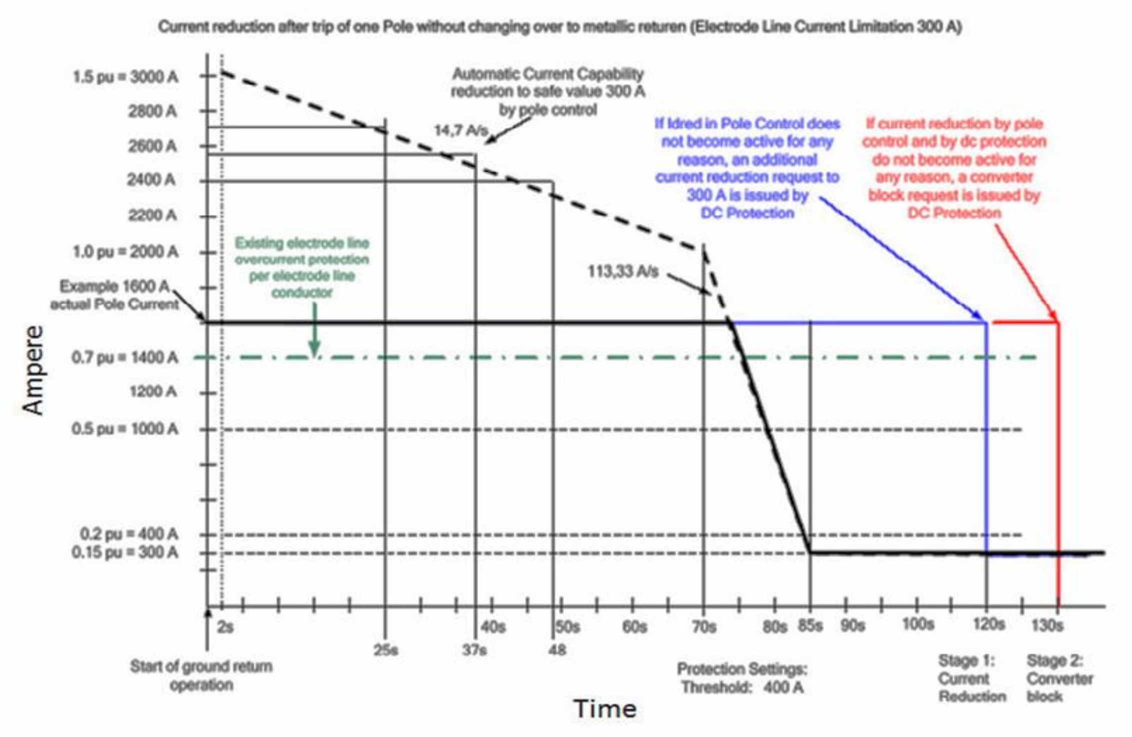

Figure 4: Electrode current reduction characteristics

As can be seen from the figure above the current reduction following tripping of a pole happens in stages. At first the current reduces to 2000 A in 70 seconds at the rate of 14.7 A/s followed by a steeper slope of reduction to 300 A in 15 seconds at the rate of 113.33 A/s. If current reduction in pole control does not become active for any reason, an additional current reduction request to 300 A is issued by DC Protection 120 seconds after pole tripping. If current reduction by pole control and DC protection do not become active for any reason, a converter block request is issued by DC protection 130 seconds after pole tripping. Frequency profile recorded at 400kV Bangalore substation during tripping of one pole of HVDC Talcher Kolar and the course of events is shown in Figure 5.

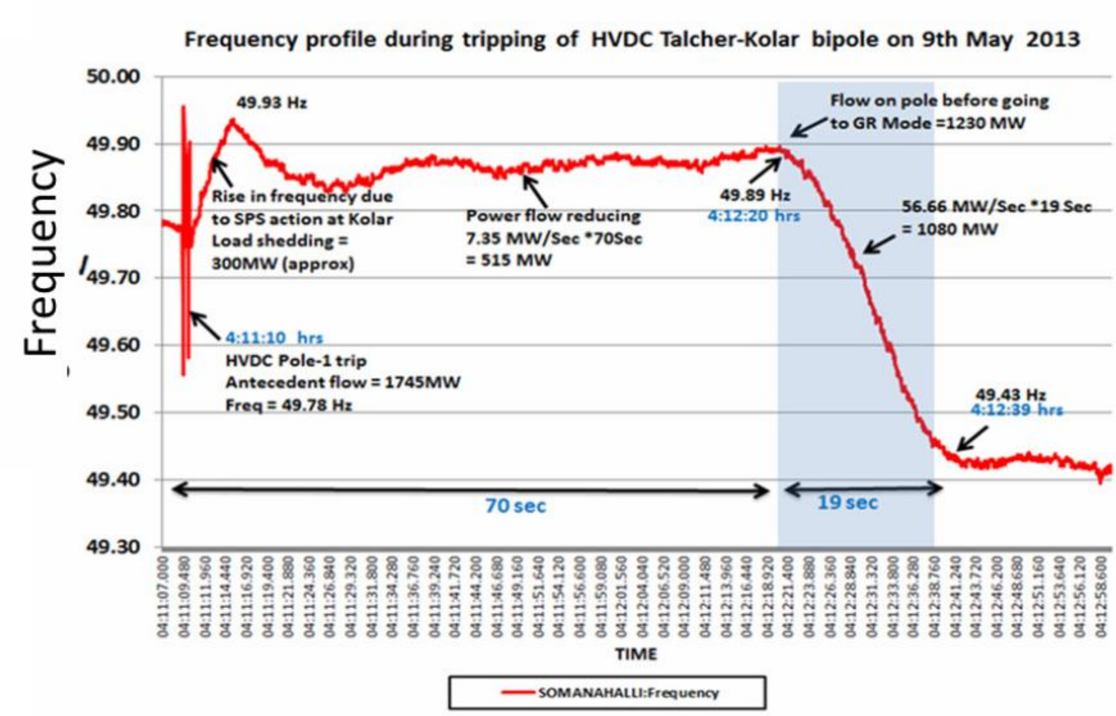

Figure 5: Somanahalli frequency and sequence of events

Following the HVDC Pole-1 tripping, SPS at Kolar acted [1] resulting in Load Shedding of 300 MW approximately and as a result the frequency increased momentarily. The flow in the line reduced from 1745 MW at 4:11:10 to 1230 MW at 4:12:20 (1745-1230 = 515 MW in 70 seconds) i.e.

14.7 A/s * 500 KV = 7.35 MW/s and

7.35 MW/s * 70 s = 515 MW.

Then second stage of current reduction happened where power flow reduced to 150 MW in 19 seconds (1230 – 1080 = 150 MW). This can also be verified as,

113.33 A/s * 500 KV = 56.66 MW/s and

56.66 MW/s * 19 s = 1076 MW.

The Somanahalli 400 kV bus voltage as seen in PMU plot is shown in Figure 6. The plot shows how the filter banks are tripped one by one to reduce the flow on the line. As can be seen that the bus voltage is ramped up to reduce the flow and then the filter bank is tripped. This is performed until the flow reduces to the required level. This method of gradual reduction of current helps in avoiding the frequency to dip suddenly and also allow for control actions to be taken so as to maintain the frequency.

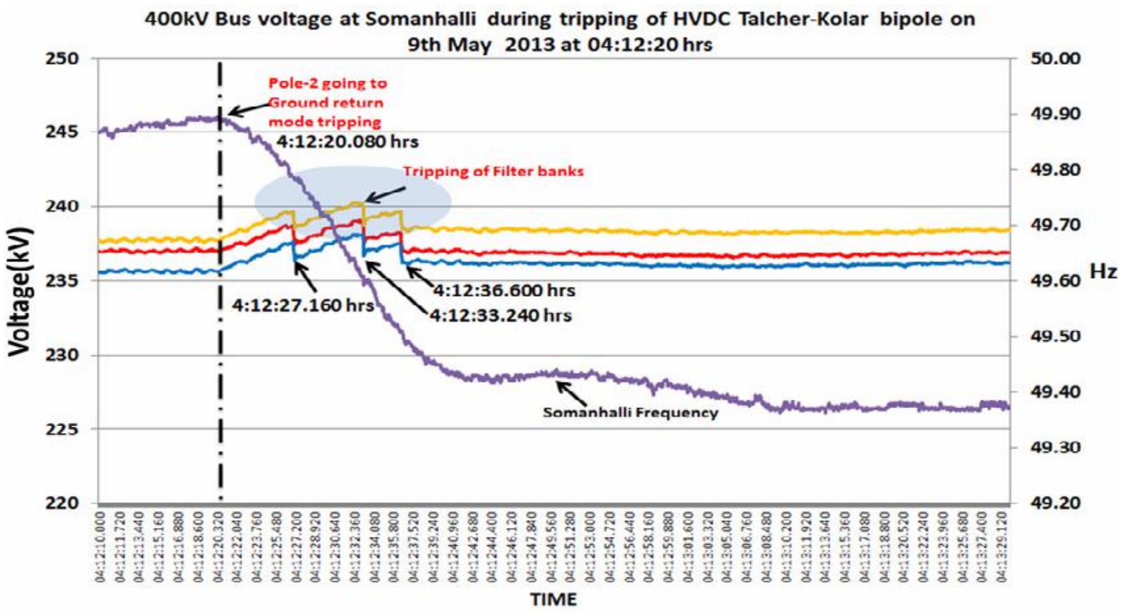

Figure 6: Somanahalli Bus Voltage plot and sequence of events

IV. CASE STUDY III

Behavior of different switching actions and its effect can be clearly seen using PMU data in Fig. 7 and Fig. 8. Following is one of the examples of filters switching at Kolar and its effect on Bangalore Bus voltage for blocking of Pole -2 of HVDC Talcher – Kolar due to HVDC line fault, on 19.05.12, 16:14 hrs. As power order is changing filters are being switched off, depending upon power flow the effect of same can be clearly noticed in Reactive power flow and Somanahalli voltage.

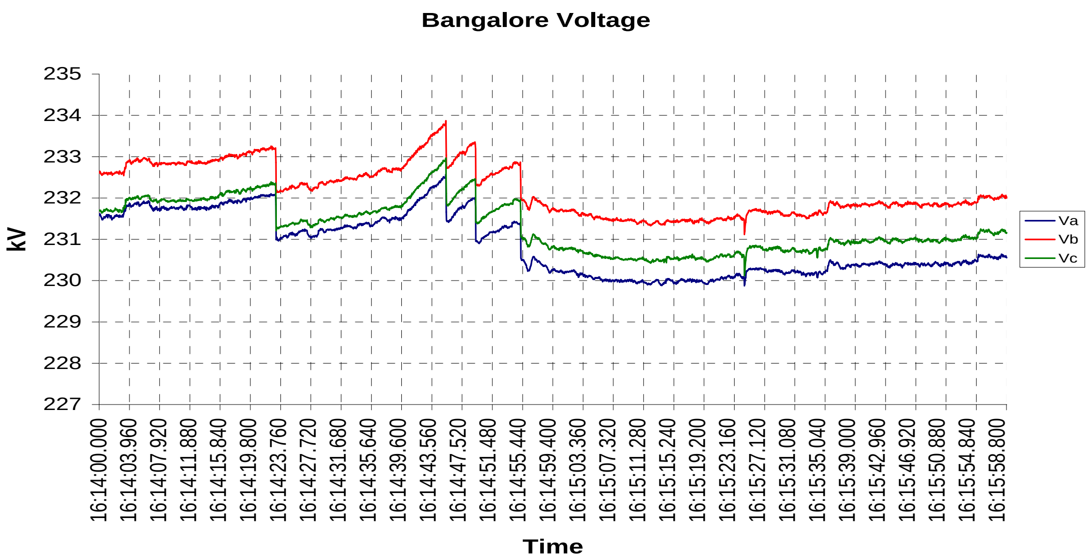

Figure 7: Bangalore Bus Voltage PMU plot

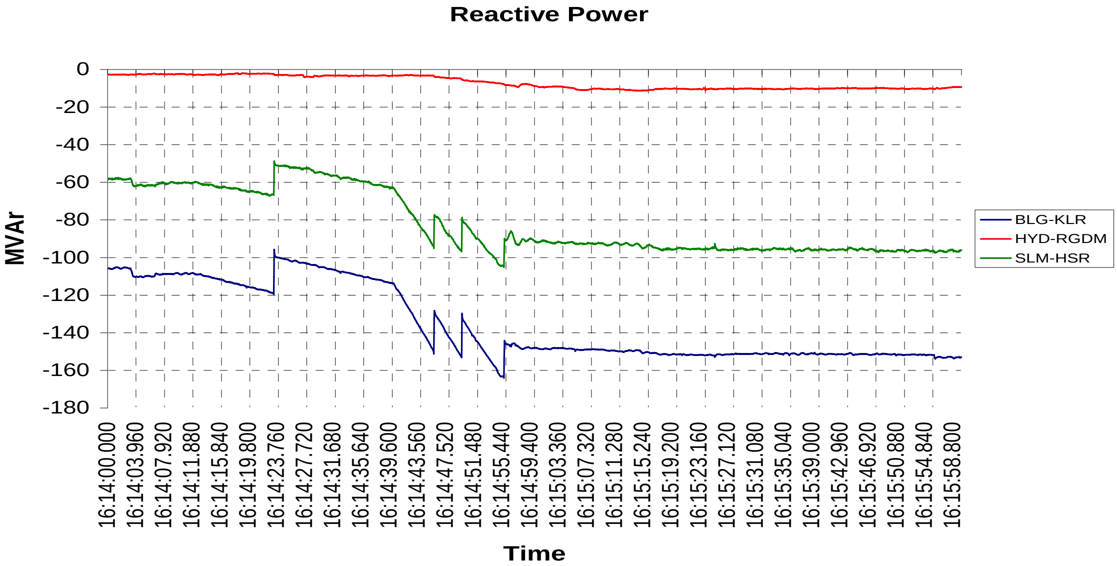

Figure 8: Bangalore Reactive Power PMU plot

V. Future Scope

Low frequency oscillations are generator rotor angle oscillations having a frequency between 0.1-2.0 Hz. The synchronisation of NEW grid with the SR grid on 31st December 2013 through the 765 kV Sholapur-Raichur line has made the study of these oscillations even more necessary as a contingency such as generation unit outage or a major line outage such as the Talcher-Kolar HVDC link results in oscillations of severe magnitude. One such incident is where oscillations were seen on the Sholapur-Raichur line due to AC LV side fault at Talcher.

On analysis of the PMU data using Prony Analysis [4] the dominant mode obtained was 0.2 Hz which is an inter-area mode with a damping ratio of approximately 10 %. The mode frequency was the same for all oscillations seen this line but they die out in 20-25 seconds. If the oscillations are sustaining in nature then it can result in catastrophic events such as black outs too as has happened in US in 2003 [2].

HVDC controls act as a stabilizer that can be used to damp this mode as the controls can be used to modulate the power flow. By choosing appropriate control signals which can be used as a feedback for control of the flow (including remote signals through wide area measurements) that have high observability can help in damping of oscillations [3]. Hence choice of appropriate signal is foremost important in stabilizer control design. The stabilizer design is shown in Fig. 9.

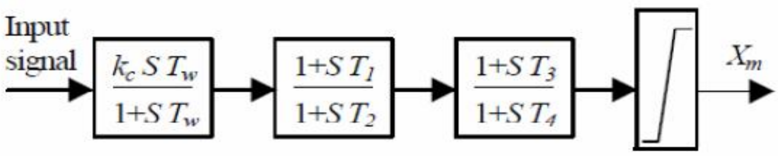

Figure 9: Stabilizer Control design

The stabilizer consists of a washout block to avoid controller response due to dc offset, a lead-lag compensator which provides the lead characteristics and a limiter to improve controller response to large deviation in input. The design basically is to tune the lead-lag block such as to get the required characteristic to damp the particular mode and also modes in the neighborhood.

CONCLUSION

The HVDC control response to various circumstances such as commutation failure, pole tripping and pole blocking, filter tripping have been captured very well using PMU data which cannot be observed using SCADA. These behaviors can be used in signature analysis i.e. each event leaves behind a particular signature of its happening which can be used in real time analysis and control. Automated systems with predictive tools that can detect such behaviors can be developed in the future which can assist the operator to take decisions dynamically. More so PMU data also can help the operator in identifying whether the necessary control action has taken place or not. On-line monitoring for low frequency oscillation helps us in identifying the mode of oscillation which thereby can be used in tuning of the HVDC controller. Such insight would be valuable in harnessing fast HVDC controls to mitigate contingencies reliably in a highly meshed network like the Indian Grid.

DISCLAIMER

The views expressed in the paper are the opinion of the authors and may or may not be that of the organization to which they belong.

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