Impact on voltage due to high power HVDC operation at low fault level

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SYNOPSIS

In this paper, emphasis is on operational issue of HVDC station at Biswanath Chariali (BNC). There is an issue of heavy spikes in voltage in NER Grid at the time of tripping of +/- 800 kV HVDC Biswanath Chariali-Alipurduar-Agra pole at high power order due to low fault level of NER Grid and disconnection of AC filter banks at an interval of 1 second. Reactive Power support for Multi-terminal HVDC operation at Biswanath Chariali node is in discrete manner. In case of switching of filter banks, there will be step change in voltage. Reactive power injection at BNC node will be more than required due to the size of shunt capacitors and harmonic filters. In case of load throw or power ramping down condition, it creates transient in voltage. It becomes very difficult for system operator to mitigate this dynamic over-voltage condition in low fault level in NER Grid without synchronous condenser and FACT devices such as SVC / STATCOM. Dynamic over voltage condition is mitigated with shunt reactors and opening of 400 kV lines which are not effective means of control.

KEYWORDS

HVDC, Power order, Low fault level, GR, MR, RVO, RPC, GRTS and MRTB

1. INTRODUCTION

Indian power system is one of the largest bulk power systems in the world and has the fastest growth rate. North-Eastern Regional (NER) Grid is the smallest of the 5 operational Regions of Indian Power system with about 2 percent share of the Peak Demand Met of India. North Eastern Regional Load Despatch Centre (NERLDC) is the Apex body to ensure integrated operation of the NER Grid of India as mandated by the Electricity Act, 2003. NERLDC supervises the activities of seven State control areas and Eleven Inter–State Generating Stations (ISGS) [1].

A multi-terminal HVDC transmission system has more than two converter Stations. A multi-terminal HVDC transmission is more complex than an ordinary point-to-point transmission. In particular, the control system is more elaborate and the telecommunication requirement between the stations becomes larger. There are two possible schemes for Multi Terminal Direct Current (MTDC) systems: Constant Voltage Parallel Scheme and Constant Current Series Scheme. The case presented in this paper is in Constant Voltage Parallel Scheme [2],[3].

1.1. Circuit Diagram

The North Eastern Region (Biswanath Chariali) – Eastern Region (Alipurduar) - Northern Region (Agra) HVDC link is the world's first Multi-Terminal project at +/- 800 kV, linking Rectifier Station at Biswanath Chariali and Alipurduar, with Inverter Station at Agra. Power flow order from BNC & APD to Agra is 3000 MW each and in case of reverse power transfer from Agra to BNC is 1000 MW.

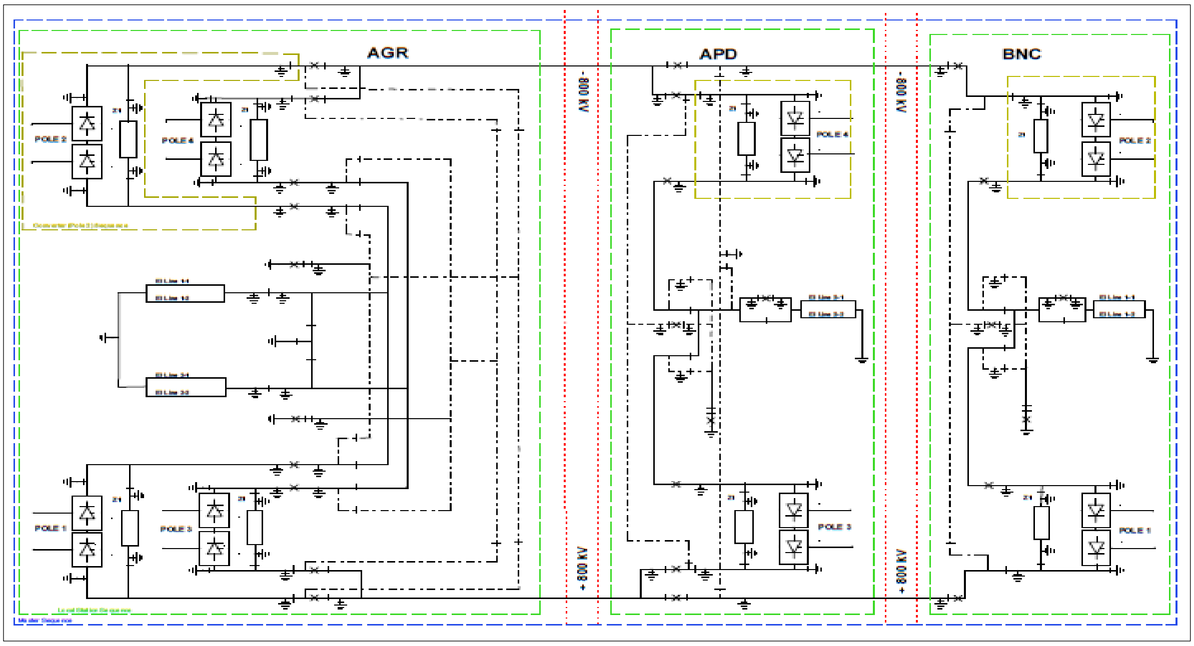

Fig. 1. Representation of Multi-terminal HVDC BNC –APD – Agra Link

The system considered has been represented in Fig. 1. 2 X 3000 MW Multi - Terminal HVDC Stations, enables power transfer between North-Eastern, Eastern and Northern Regions in asynchronous mode. Total MVAR Capacity of AC filter banks at BNC, Alipurduar and Agra are 1983 MVAR, 1992 MVAR and 3630 MVAR respectively.

2. CASE STUDY

Ranganadi Power Station, Pare Power Station and Arunachal Pradesh Power System (except Khupi & Deomali areas) were connected with the rest of NER Grid through 400 kV BNC - Ranganadi 1 & 2 Lines as shown in Fig. 2. 132 kV Gohpur- Nirjuli line was kept opened to control over-loading of 132 kV Nirjuli - Lekhi line. At 09:22 Hrs on 29.08.18, +/- 800 kV BNC – Agra Pole 1 tripped and subsequently, 400 kV BNC – Ranganadi 1 and 2, 400 kV Balipara – BNC 1, 132 kV Ranganadi – Pare 2 and 132 kV Pare – Itanagar lines tripped on Over-voltage.

Due to the Grid Disturbance, total generation loss was around 175 MW (Ranganadi: 120 MW and Pare: 55 MW) and total load loss in Arunachal Pradesh State Power System was around 55 MW in Chimpu and Lekhi area of Arunachal Pradesh.

2.1. Operational Issue

In case of Pole tripping, filter banks will also be tripped simultaneously. However, for Power ramping down as in this paper, delay in filter sub bank disconnection shall be at an interval of 1 second. Reason for delay is to avoid bulk switching at the same time as it can result in severe transient in voltage due to low fault level of NER Grid. This transient is reflected in AC side which creates oscillation in voltage and current which could further lead to mal-operation of Distance Relays in AC side. Maloperation of Distance Relays during the power swing resulted in 2012 India blackouts [4]. During tripping of Pole with high power order, temporary over-voltage was observed on AC grid. The reason was the reduction in reactive power consumption at the converter terminal without a corresponding reduction in the generated reactive power from the compensation equipment such as filters and the shunt capacitor banks which remained connected to the system for few milli-seconds.

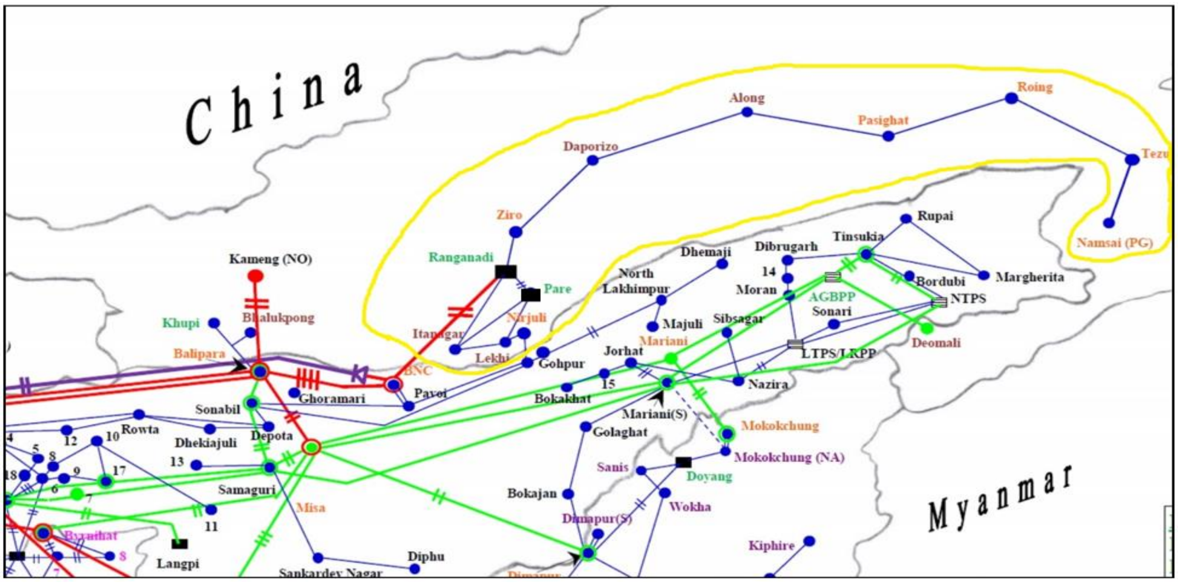

Fig. 2. Representation of affected NER-Region

Different control actions such as increased firing angle operation and filter tripping or Dynamic voltage support compensation scheme could be adopted to limit over voltages in case of Reduced Voltage Operation (RVO) operation [5]. During High Power Order (2000 MW) testing with BNC as rectifier and Agra as inverter, the voltage of 400 kV nodes (Bongaigaon, Balipara, Ranganadi, Biswanath Chariali, Misa and Azara) was around 380 kV because of more demand of reactive power compensation at BNC node. During this period, very low voltage was reported by SLDC Assam in their downstream system. Reference [6] proposed requirement on Reactive Power Control (RPC) is that AC voltage step change (pu) should not exceed specified AC voltage expressed as

$$\Delta V = \frac{Q_{switch}}{SCL_{min} - Q_{total}} \tag{1}$$

Where SCL_{min} is the minimum short circuit level at AC system (MVA) in which switching takes place, Q_{switch} is the Reactive power step to be imposed and Q_{total} is the total Reactive power connected to the converter including the Reactive power to be switched. In this paper Reactive Power Demand versus Active flow at BNC node for Mono-Polar Auto mode of operation is presented in Fig. 3.

Reference [7] proposed two Bipoles can transfer power through same HVDC line or by separate line with different configuration such as with Dedicated Metallic Return (DMR) or without DMR. Both Bipoles can run with different configuration as per availability of converter, line and requirement of power. The details of protocol received from BNC with master control at Agra, for Ground Return to Metallic Return, are as follows: Changeover from Ground Return (GR) to Metallic Return (MR) can be done at BNC by closing of Ground Return Transfer Switch (GRTS) and opening of Metallic Return Transfer Breaker (MRTB). Reference [6] proposed principle of Ground return to Metallic return mode as shown in Fig. 4. Changeover from MR to GR at BNC can be done by closing of MRTB and opening of GRTS as shown in Fig 5.

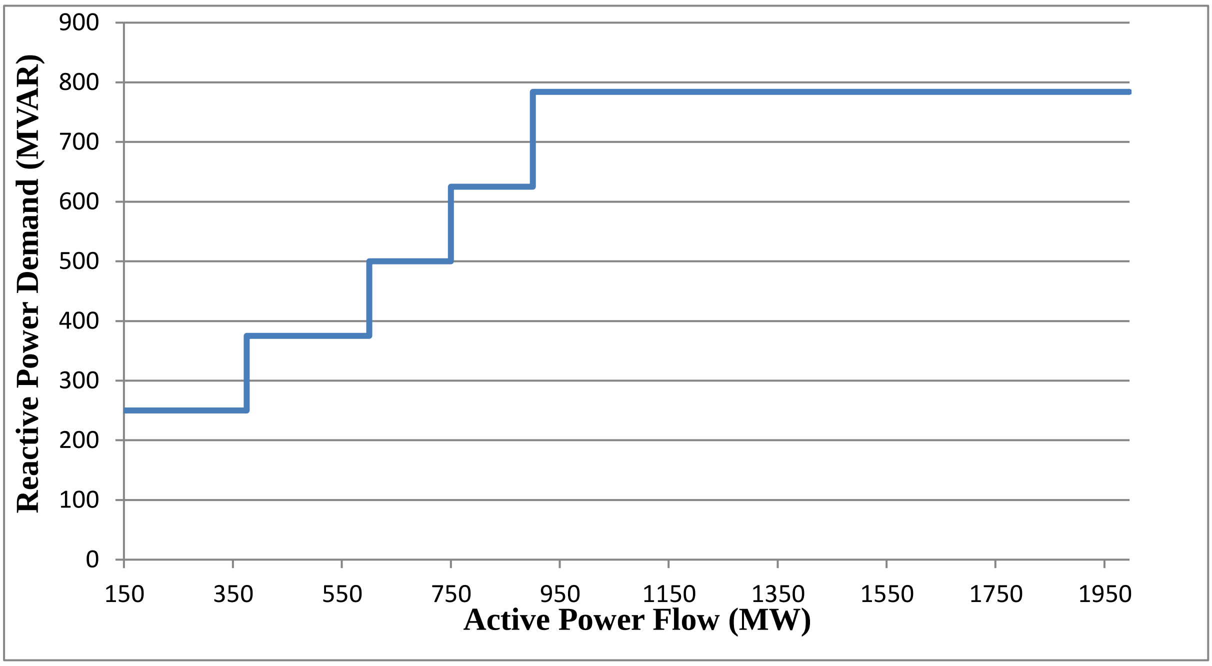

Fig. 3. Reactive Power Demand versus Active Power flow

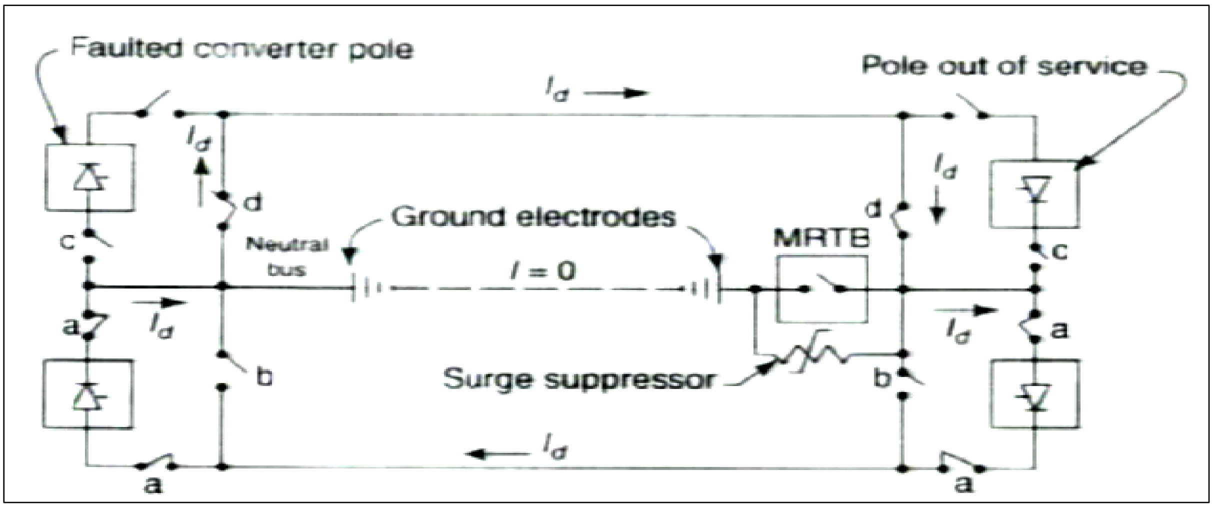

Fig. 4. Circuit Diagram for Ground return to Metallic Return mode

The changeover from GR to MR and vice versa can be executed from Agra by changeover sequence of Master Control at Agra. On the day of tripping, the changeover sequence was carried out by Agra and it was successful at BNC end but likely due to closing of line earth switch instead of opening it by controller of Agra at Agra end, +/- 800 kV BNC – Agra Pole 1 tripped immediately at Agra on Metallic Return Conductor Ground Fault Protection after transfer from ground return mode to metallic return mode.

Due to power order down command being received at BNC, Pole as well as filter banks was in service. With no dc power flow immediately after tripping of Pole 1 at Agra, the AC bus voltage rose significantly at BNC since the filter sub banks were connected. However, Bus Harmonics Over-Voltage protection operated at BNC and Y block was ordered resulting in tripping of Pole 1 at BNC.

The duration of power order down signal being received at BNC and tripping of pole was around 393 milli-seconds as shown in Fig. 6. However, voltage was stabled in Balipara PMU after 360 milli-seconds.

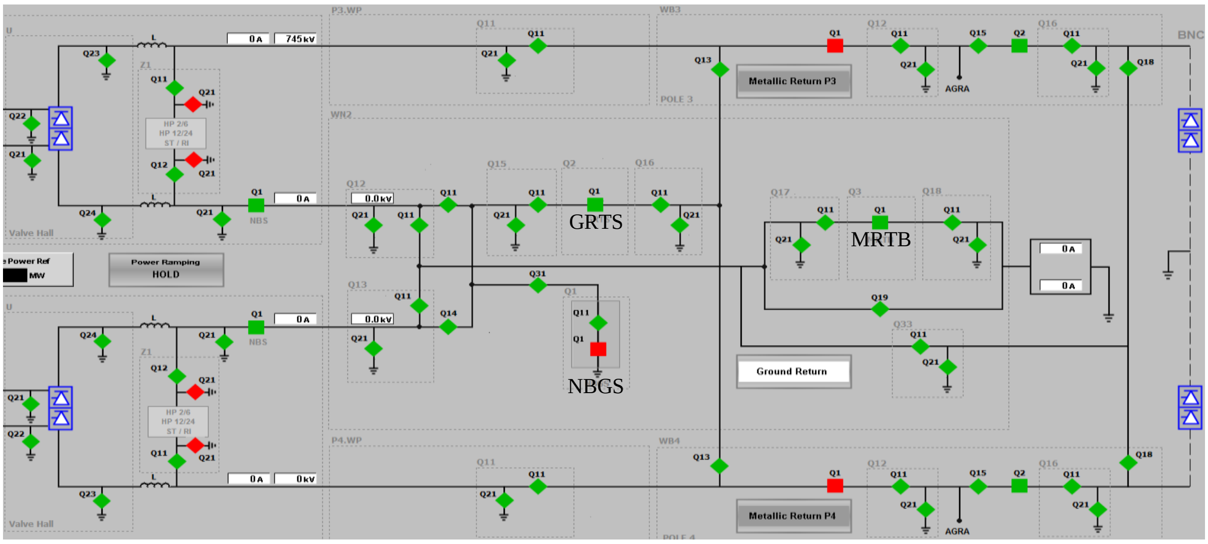

Fig. 5. Switching Diagram at BNC

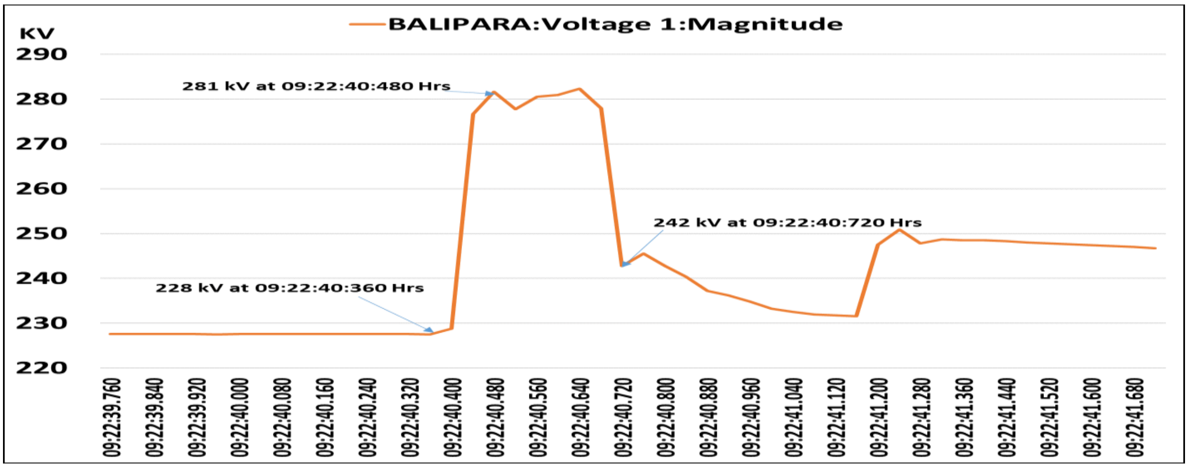

Fig. 6. Duration for the tripping of pole

Reactive power controller is required to reduce dynamic Over Voltages. It improves the system performance and brings back the system into stable state quickly. Reactive power of a system is dependent on magnitude of the AC voltage and hence it is used to get the modulation index of the PWM waveform in VSC based HVDC operation. With this control, the HVDC system is made self - sustaining in reactive power supply to the loads [8]. In this case, as NER has low fault level, switching of filter banks may create transient in AC side of NER Grid due to which RPC controller may not perform well. Reductions in power transfers are referred to as runbacks. The runbacks are controlled to a rate of 10 MW per second to minimise the frequency disturbance in the AC system [9].

In case of Bipolar operation of +/- 800 kV HVDC Biswanath Chariali-Alipurduar-Agra pole, maximum ramp rate is 300 MW/min and minimum ramp rate is 1 MW/min. Table 1. shows the Short Circuit Level of NER Grid and Filter Selection Matrix with change in power-order during Bipolar mode of operation as per PSS@E studies. It shows low effective short circuit level of NER Grid at high Power order condition. Fig. 7 represents increasing trend of reactive power demand with increase in Power order.

Table 1: Short Circuit Level of NER Grid and Filter Selection Matrix

Sl No.	Pd (MW)	Qd (MVAR)	Qf (MVAR)	Filter Selection Matrix (MVAR)	SCL (MVA)
1	200	82	125	125 (1*125)	6893
2	500	250	250	250 (2*125)	6922
3	1000	604	604	604 (2*160+1*159+1*125)	6893
4	1500	1063	1078	1078(3*160+2*159+1*155+1*125)	6893
5	2000	1612	1663	1663(1*160+2*159+2*155+7*125)	6893
6	2500	2002	1983	1983(3*160+2*159+2*155+7*125)	6893
7	3000	2041	1983	1983(3*160+2*159+2*155+7*125)	7272

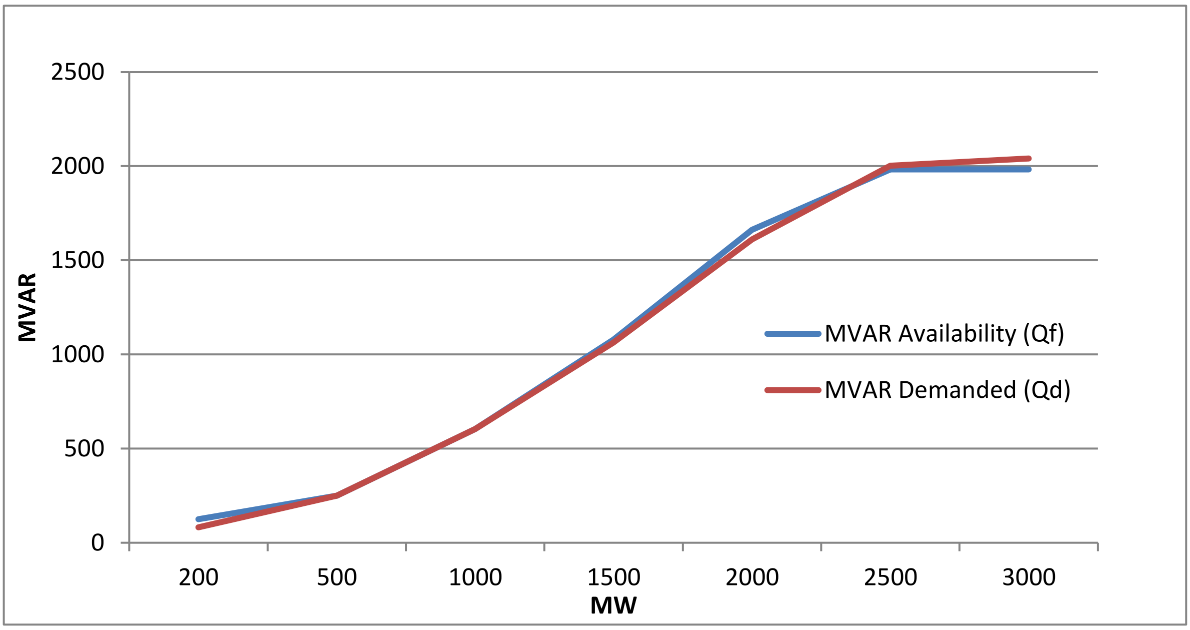

Fig. 7. Power order versus reactive Power demand

3. ANALYSIS OF DISTURBANCE RECORDER (DR) AND EVENT LOGGER (EL) OUTPUT

3.1. Tripping of 400 kV Biswanath Chariali – Ranganadi 1 Line:

Biswanath Chariali: DR output as shown in Fig. 8 indicates over-voltage Stage I start in all the R-Y-B Phases at 09:22:41.437 Hrs. The line tripped at 09:22:41.556 Hrs due to DT received.

Ranganadi: DR output as shown in Fig. 9 shows over-voltage protection trip operated at 09:15:04.104 Hrs (not time synchronized with GPS). As per the present settings of 120% with 100 milli-seconds delay for Stage II protection kept at Ranganadi, over-voltage protection operated at Ranganadi (294 kV in R & B phases ~corresponds to 127% of nominal voltage).

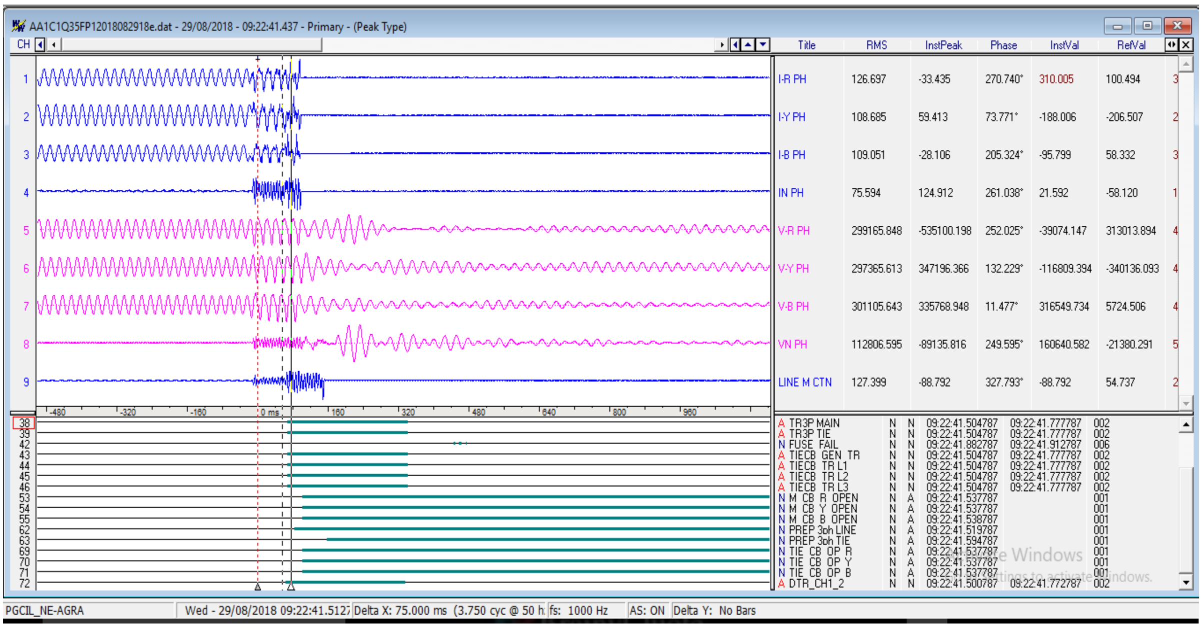

Fig. 8: DR output of BNC for 400 kV BNC-Ranganadi 1 line

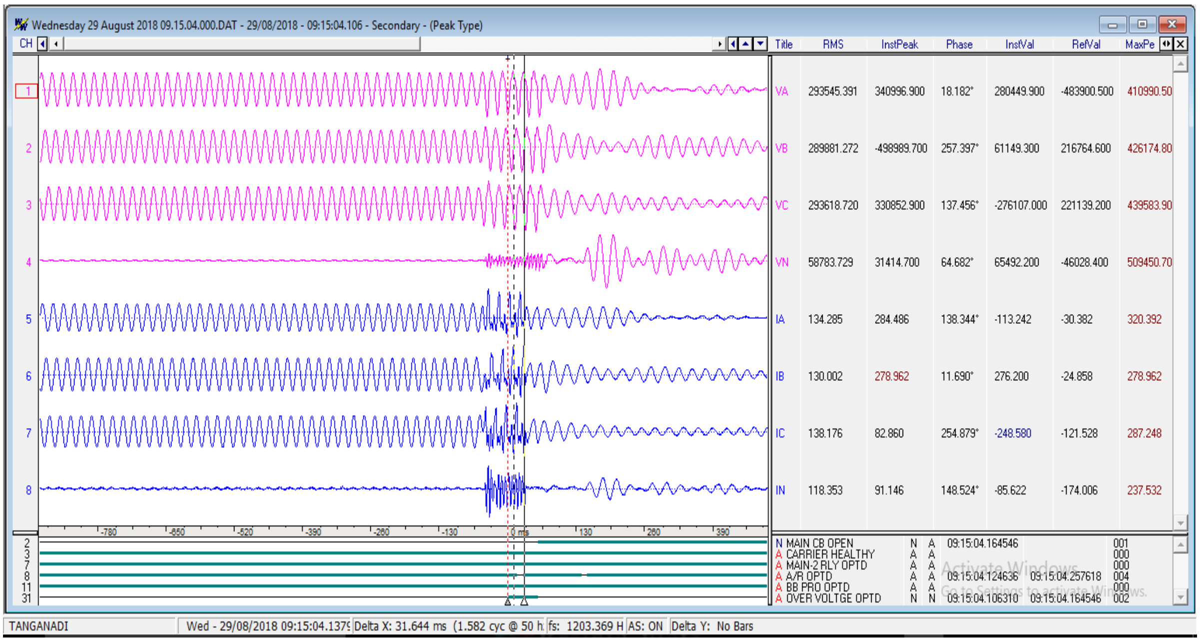

Fig.9: DR output of Ranganadi for 400 kV BNC-Ranganadi 1 line

3.2. Tripping of 400 kV BNC – Ranganadi 2 Line:

Similar to signature of 400 kV BNC – Ranganadi 1 Line, it is observed that BNC tripped at 09:22:41.672 Hrs due to DT received while Ranganadi tripped at 09:22:40.567 Hrs due to over-voltage protection (297 kV in B phase ~corresponds to 128% of nominal voltage).

3.3. Tripping of 400 kV Balipara – Biswanath Chariali 1 Line:

Biswanath Chariali: As per DR output, line tripped at 09:22:41.591 Hrs due to DT received.

Balipara: As per DR output, over-voltage Stage-I triggered in all the R-Y-B Phases at 09:21:40.384 Hrs which deactivated subsequently. No tripping/ protection tripped was observed from DR output. However, it is suspected that electro-mechanical over-voltage relay may have operated resulting in sending DT signal to BNC.

3.4. Tripping of 132 kV Ranganadi – Pare 2 Line

Pare: As per DR output, any trip triggered at 09:22:40.430 Hrs. No over-voltage protection trip was triggered in DR output. However, the voltage in the R, Y and B phases were 96 kV, 91 kV and 88 kV which corresponds to 126%, 120% and 116% of nominal voltage.

As per the settings given by Pare for 132 kV RHEP – Pare 2 Line, settings for over-voltage Stage II is 115% instantaneous.

Ranganadi: No tripping reported.

3.5. Tripping of 132 kV Pare – Itanagar Line:

Pare: As per DR output, no over-voltage protection trip was triggered. However, the voltage in the R, Y and B phases were 96 kV, 92 kV and 88 kV which corresponds to 126%, 121% and 116% of nominal voltage.

Also, as per the settings given by Pare for 132 kV Pare - Itanagar Line, settings for over voltage Stage II is 115% instantaneous.

No tripping was reported at Itanagar.

3.6. Analysis from Transient Fault Recorder of BNC:

BNC: As per TFR output as shown in Fig. 10, High AC voltage and Low AC and DC current was detected at 09:22:41.417 Hrs. Retard was also triggered at the same time. Y block ordered at 09:22:41.632 Hrs. Thereafter, AC Converter Bus and AC Filter Bus Harmonic over-voltage protection tripped the Converter Transformers and AC Filters leading to reduction of AC Voltage.

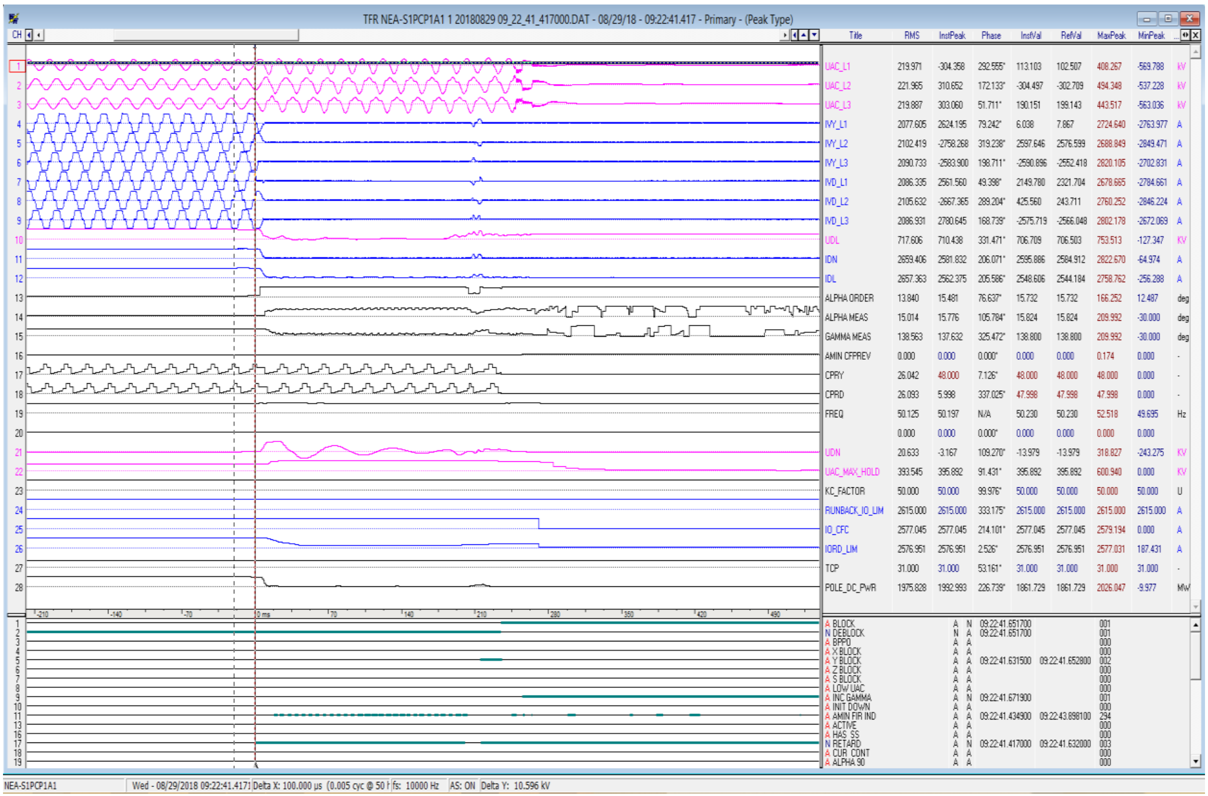

Fig. 10: TFR output of BNC

4. CONCLUSION

There are various solutions for mitigating the Reactive Power and Dynamic over voltage problem such as FACT devices, Synchronous Condenser and forced commutation [2]. Solution for mitigating these issues need to be planned at the earliest otherwise it will create problem when Renewables penetration will be high which may also create severe transient in lean Hydro period.

5. ACKNOWLEDGEMENT

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