Generator MW Deviation in AC Transmission Line due to HVDC Line Load Fluctuation in Western Grid

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Abstract— In this paper, transient stability analysis was focused on Generator MW deviation in AC transmission line due to HVDC transmission line Load Fluctuation in western Grid. The UMPP Mundra Power project is introduced here and for analysis, data of MW variation with reactive power fluctuation is taken from historian data of PI software that take data from tag of monitoring relay. The dynamic performance and the interaction between AC and DC systems during serious disturbance were researched by detail analysis. The research will bring important and significant reference for further operation and stability control of HVDC and AC system.

Key words: AC transmission line, MW deviation, HVDC, Transient Stability, Control Strategy

I. INTRODUCTION

Since the first High Voltage Direct Current transmission project was commissioned into commercial operation in 1991 in India was Rihand –Dadri connecting Thermal power plant in Rihand ,Uttar Pradesh (Eastern Part of Northern Grid) with Dadri (Western Part of Northern Grid). HVDC has been developed so rapidly that it has been widely applied in such fields as large power transmission over long distance, interconnecting two asynchronous systems, power transmission through submarine cables for supplying power to islands and so on. Compared with three-phase AC transmission systems, conventional HVDC is superior in the following aspects [1]: Firstly, HVDC need less cost in constructing and operating; Secondly, it needs not keep operating synchronously between the two AC systems; Thirdly, it is easy to control and adjust power flow, etc. Among the many HVDC long transmission schemes around the world, very few operate in parallel to AC transmission of comparable capacity. Problems for parallel AC/DC operation is primarily related with the coordination between AC and DC power flows and how each system reacts to any disturbance [2]. It is well known that AC transmission systems have the inherent means to reschedule their power flows and to provide timely and sufficient synchronizing torque to secure such flows following disturbances such as AC faults, load rejection or generator tripping, etc. How a HVDC in parallel to AC system reacts in those situations has always been a central question, particularly for planning and daily operation of such a complex scheme. In reference [3-6], the interaction action between AC and DC parallel transmission system were studied, the theory and operation rules of such power system were demonstrated with example of event occur at western grid and data taken from PI software. Results show that HVDC schemes in parallel operation with AC transmission are prone to both transient swing angle and voltage instabilities. And the risks of instability will increase during disturbances. In reference [7-9], research on advance control strategy for a HVDC scheme in parallel operation with AC systems was discussed. By these unconventional control strategies, the HVDC scheme can actively participate in the instantaneous rescheduling of power and improve the dynamic performance of power network. In reference [10, 11], a real AC and DC parallel transmission system in western India was studied from operation and control aspects.

The Mundra Power project is first UMPP project in India which Generation is 4000MW with 400KV AC transmission line directly connected to Western Grid through substation. Also another power project nearest to it has HVDC transmission mission line which is connected to western grid. As a result, the stability problem in operation is very critical for Grid during transient fault occur in HVDC line.

In this paper, transient stability analysis was focused on the TATA Mundra UMPP Generation MW deviation due to load fluctuation in HVDC transmission line running in western grid with AC transmission line system.

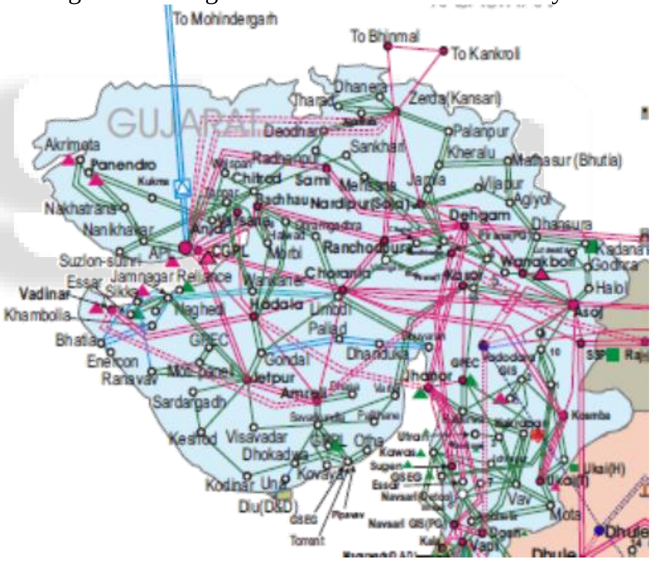

Fig. 1: Power Map of Western Gujarat Grid.

II. MUNDRA-UMPP AC TRANSMISSION LINE AND ADANI – MUNDRA HVDC LINE

Western Gujarat Grid have two large Power Network System consists of TATA Mundra UMPP which have generation capacity of 4000MW connected with 400KV AC transmission line and Adani Mundra which have capacity of 4620MW connected with 400KV AC transmission line and HVDC transmission line. These networks have been linked with western gird of 400 kV transmission lines. Adani HVDC line have transmission capacity if 2500MW length of 1000Km network is connected with Mundra Mohindergarh network by HVDC links. Figure 1 shows the schematic of Adani Mundra HVDC and TATA Mundra AC transmission system.

TATA power has been established first UMPP project in India at Mundra location and coal as a fuel taken from other country. Mundra UMPP power project have total capacity of 4000MW and all unit are commission and declared for commercial production in 2013.

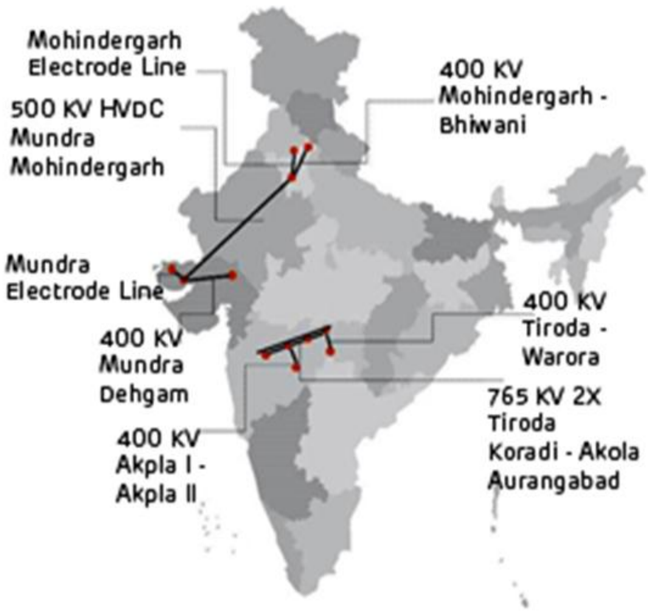

Fig. 2: 400KV and HVDC line layout

Adani Mundra HVDC transmission is a bipolar 12-pulse HVDC transmission system with rated DC voltage ± 500 kV, rated power 2500 MW, rated current 2500 A. Overhead lines have a length of 1000 km long. Adani Mundra converter station locates at Mundra station. . It acts principally as an inverter and its AC side rated voltage is also 500 kV. The Mundra HVDC transmission system operation modes include bipolar mode, monopolar ground return mode, monopolar metallic return model and monopolar parallel line ground return model. The HVDC system can be operated under rated voltage and lower voltage. The Mundra HVDC transmission normally operates in P mode (constant power control mode). I mode (constant current control mode) can be used as a back-up mode.

Adani Mundra Power have large scale thermal power plants at Mundra, they have two transmission line 400KV and HVDC. At station, Thyristor Controlled Series Compensation (TCSC) is installed to improve the transfer capability. Tata Mundra UMPP has AC transmission line connected with 400KV switchyard. The electric power capacity of Adani Mundra UMPP is 4620MW and HVDC transmission line have rated power transfer capacity is 2500MW.

The electromechanical transient of this AC and DC hybrid system was made through Online monitoring data analysis system. Mundra Tata Power UMPP has online monitored data analysis system through any event history stored and analyses after event occur though PI software.

III. MODELS FOR AC SYSTEM

For most of generators, five-order model is adopted, in which the variations of Eq″, Ed″ and Eq′ are considered. They are fit for detail simulation of salient pole synchronous generators. As for the individual small hydroelectric equipment, two-order is adopted, in which it is approximately hold that Eq’ could keep constant. Most of wind turbines are modeled as doubly-fed direct-drive wind power generators. The models of the corresponding regulators such as excitation system, speed control system and PSS, are selected and defined in the software according to the practical case.

The electric distance is relatively near between TCSC and DC lines. The TCSC is composed of two parts: fixed part and variable part. The fixed part occupies thirty percent of the total transmission line capacity and the variable part occupies fifteen percent. In the dynamic process, the TCSC acts as follows: The fixed part is sure not to be bypassed when fault occurred in trans- mission lines; The variable part is to be bypassed when three or two phase fault occurred in the line; while when single phase fault occurred, the fault phase is bypassed and the forced compensation will take action in normal phase; The forced compensation will also take action when fault occurred in neighbor line. The bypass time of TCSC is 0.05 s after fault occur.

The control logic of the variable part is shown in Figure 2. Where, P and V are measured power and voltage, which is used for oscillation control; trigger is the signal of beginning time and T forced is the continuous time of the action. The maximum compensation capacity is forty-five percent.

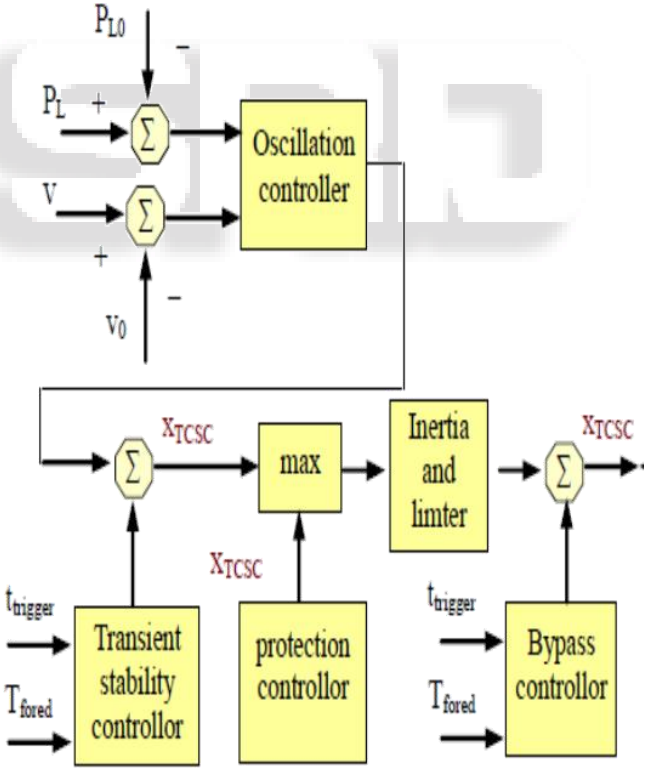

Fig. 3: Control Scheme of TCSC

IV. MODELS FOR DC SYSTEM

The DC model used in steady state calculation is shown as the following equation, in which approximation was made in reactive power calculation and in this way the equation form was much simplified.

$$\begin{cases} P_{ac} = U_d I_d \\ Q_{ac} = P_{ac} \tan\varphi \\ \cos\varphi \approx U_d / U_{d0} \end{cases}$$

Where, Ud0 is the converter transformer no-load DC voltage, Pac and Qac is the active and reactive power from AC to DC. Id and Ud is the current and voltage of DC line.

In normal operation, HVDC links required to transmit a scheduled power. In such an application, the master control layer receives the power schedule, modifies by auxiliary power control and then converts the power signal into the coordinated bi-pole current order commensurate with the DC voltage. Pole control is the core of HVDC control and activates the appropriate controller of the rectifier and inverter station according to the state of AC/DC systems. Then it produces the firing angle for both rectifier and inverter stations. The control scheme is shown in Figure 3.

Pole control at the rectifier side has a current controller, which takes the maximum and minimum current con- strains and the VDCOL into consideration. The minimum firing angle control is embedded implicitly in the current

For effective control and monitoring the HVDC system, the project activity will utilize the Supervisory Control And Data Acquisition (SCADA) system at both convertor stations. The function of the control system would be to:

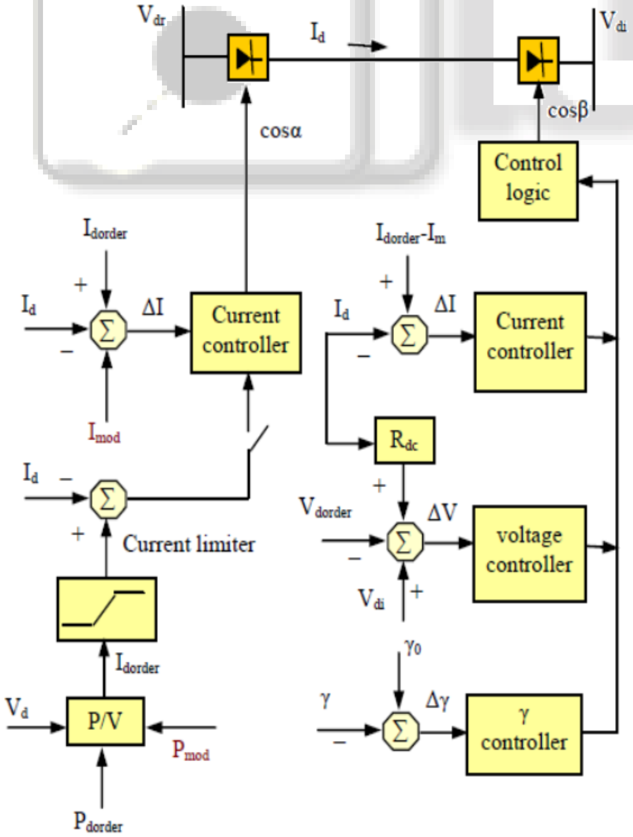

Fig. 4: Control Scheme of DC system

- Control system quantities such as DC line current, transmitted power or frequency of either of the two connected AC network with sufficient accuracy and speed of response.
- Ensure stable converter operation in presence of small system disturbances.

Controller by angle limits. Pole control at the inverter station includes a voltage controller, a constant current controller and a constant extinction angle controller. Current error Im provides a transition between the current control and voltage control to facilitate control stabilization. The shift logic of these controllers is implemented by:

$$I_d = \frac{U_{d0r}\cos\alpha - U_{d0i}\cos\gamma}{d_{xr} + R_d - d_{xi}}$$

Where: dxr, dxi are the equivalent resistance of the rectifier and inverter. Rd is the resistance of DC line. α and γ correspond to the rectifier ignition angle and inverter extinction angle.

When situation needed, additional control will be joined through Pmod or Imod to fully exert the DC features of fast power control and improve the dynamic performance of AC system.

V. CRITERION FOR TRANSIENT STABILITY

According to power system stability guideline of India, to keep transient stability, the following conditions must be satisfied at the same time:

A. *Angle Stability:*

after disturbance, any rotor angle between two generators in the same AC system takes on a damping oscillation.

B. *Voltage Stability:*

The continuous time of low voltage under 0.75 pu is within 1s. The voltage of pivot buses is above 0.8 pu when the fault is clear.

C. *Frequency Stability:*

the frequency collapse will not happen with secure measures such as loads shedding and generator tripping. The frequency can restore to the normal level and the large unit operation will not be affected.

VI. TRANSIENT STABILITY ANALYSIS

Transient occur when any fault occur in the gird or large source of power deviated in the system due to tripping of large power plant and transmission line fault. Transient stability criterion for the studied system required the system to be stable after clearing of any fault which occurs within the system or outside the system (GRID).For AC system transmission line the worst condition occurs when three phase permanent fault occur and for DC system the worst condition occurs when bipolar blocking happens. Stability measures data are taken for Tata Mundra UMPP AC system due grid disturbance which produce by HVDC line.

A. *Dynamic Behavior of AC Generator due to Fault in HVDC system:*

This is case studied about Generator MW deviation due to HVDC line fault in the western Grid. The reason is that Reduced Voltage operation (RVO) of HVDC Mundra Mohindergarh. Due to frequent faults on inverter end, HVDC Mundra Mohindergarh was in RVO operational Mode. The Fault was reflected on converter end as a three phase dip in voltage. The voltage/current of Mundra and nearby was thus getting few spikes which were observed as MW variation in the units.

As a result spike observed in MW, frequency, field current, generator terminal voltage and Power factor.

1) Generator MW Deviation:

Mundra UMPP all five unit are running at full load 830MW at time of HVDC fault which observed at 08:05:00 hrs dated 08-jan-2015 to 08:30:00 hrs dated 08-jan2015.Generator Load deviated from their normal operating limit getting few spike up to 900MW but that transient are slowly diminished with few second as shown in fig 4.In Fig MW Deviation of all five unit generator are shown with respect time and each generator have different response for transient disturbance and controller action for MW deviation.

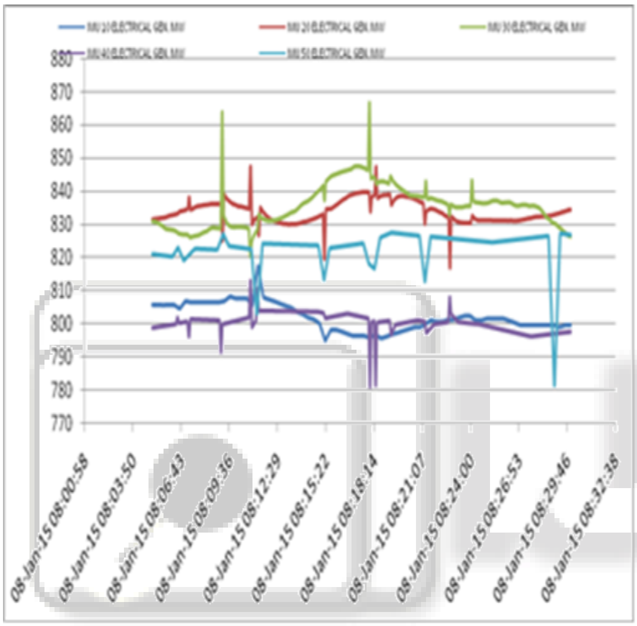

Fig. 5: MW Deviation with time.

2) Frequency Deviation:

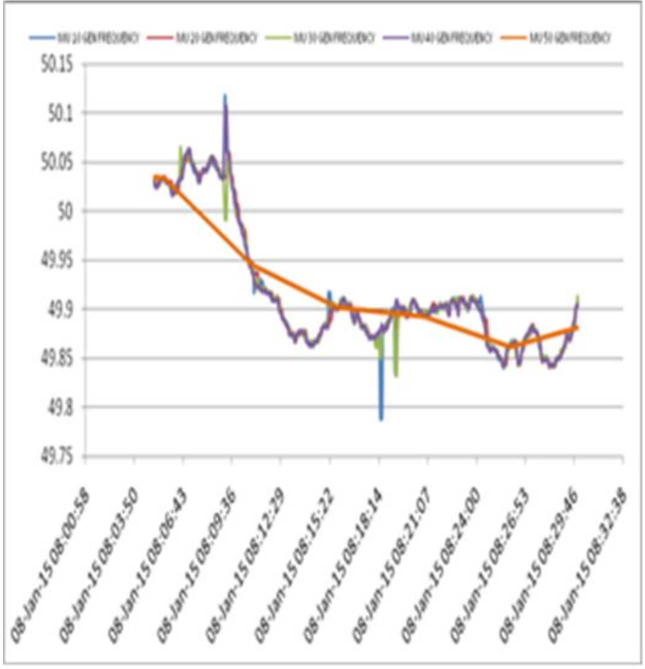

Fig. 6: Frequency Deviation with time.

When large load suddenly though off from the system due to fault occur as per occurrence report frequency deviated from normal operation frequency due to this RMP of turbine also deviated depend on the system inertia.

3) Generator Reactive Power:

Reactive power variation depends upon the system requirement, generators produce both active power and reactive power when suddenly load variation occurs in the system that produces the large variation in reactive power also. Fig shows the reactive power variation of all five units with respect to time. Sudden spike observed in graph due to transients in the system that produced by the load fluctuation in HVDC line western grid.

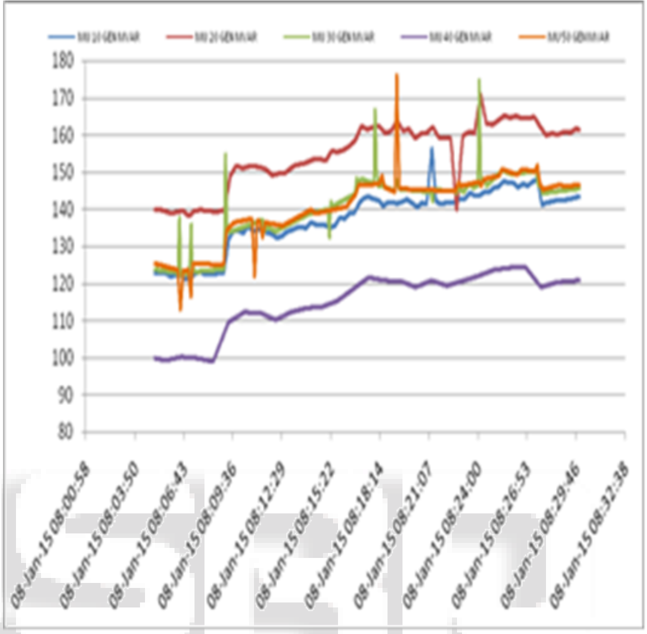

Fig. 7: Reactive power Deviation with time.

4) Generative Power Factor:

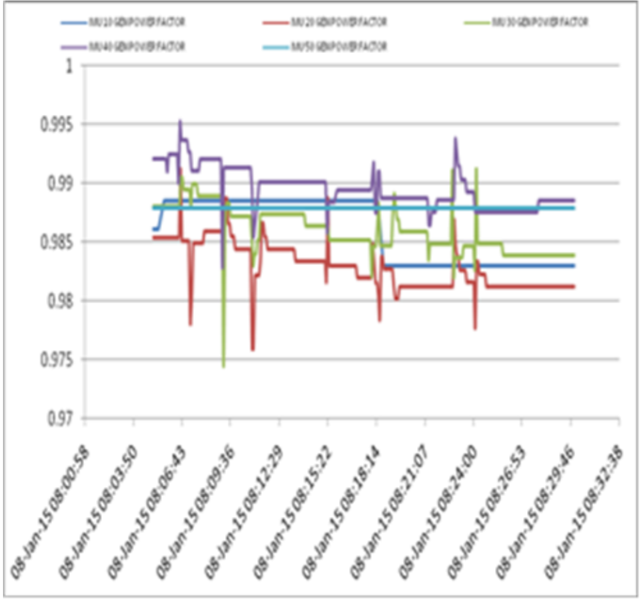

Fig. 8: Power Factor Deviation with time.

Power factor taken from the angle difference between voltage and current phases that shown variation in the system in term of lagging, leading and unity operating mode .Sudden load variation also change the power factor of generator due to transient disturbance and it also deviate the rotor angle that shows the bonding between synchronous between rotor and stator.

5) Generator Terminal Voltage:

Generator having the rated capacity of 26KV termianl voltage and 21KA generator current.After Generator setup transformer which setup the votage from 26KV to 400KV then after it conneted to the grid .During trasiend fault in the gird system termianl voltage also deviated from their noraml operating ranage.

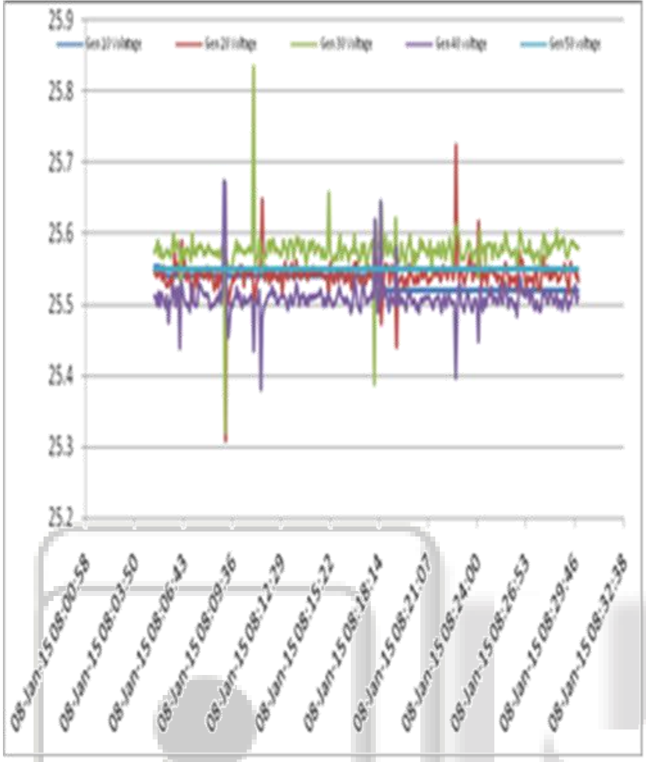

Fig. 9: Generator Terminal voltage Deviation with time.

6) Generator Field Current :

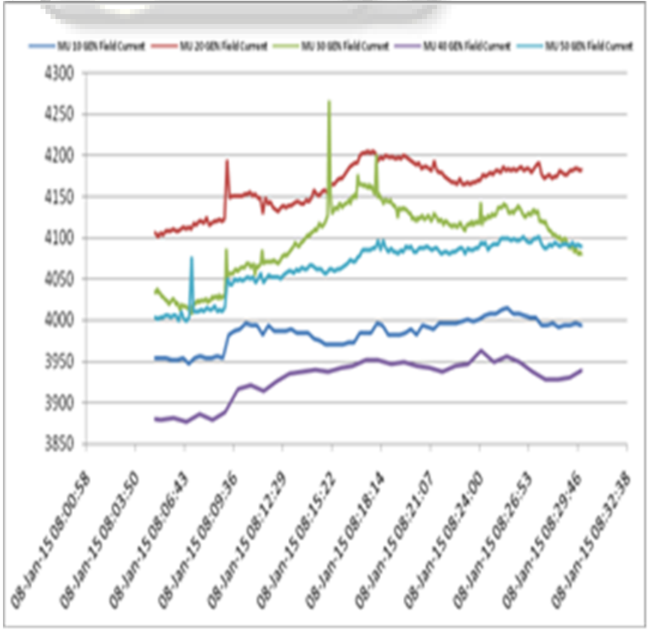

Fig. 10: Generator field current Deviation with time.

Excitation system mainten the filed current so that generator continous produce power without lossse of synocronization.During transient fault generator maintane the syncronization with gird my mainting their parameter with gird equivalent due to that geneartor field current also deviated from the normal operation range.

B. *Dynamic Behavior When DC Faults:*

When fault occurred in HVDC line, the bipolar blocking is the most serious one. In this case, mass power shift to AC lines and make a great impact on AC system. If DC can restart successfully, the oscillation can be appeased and AC system keeps stable: Else, AC system will lose stability without secure control measures.

In the above occurrence HVDC faults are occur due to lowering voltage for the HVDC line that trip the converter end that fluctuate the large power in the system.

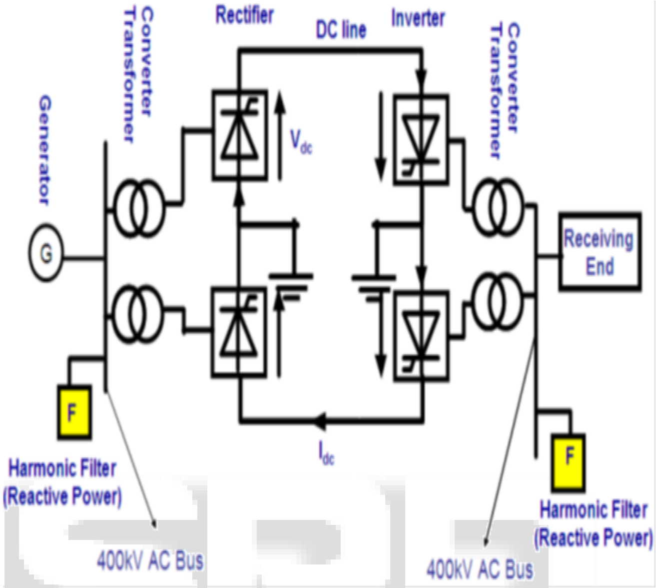

Fig. 11: HVDC transmission link

VII. CONCLUSIONS

In this paper, transient stability analysis was carried out focus on the TATA Mundra AC Transmission line MW deviation due to HVDC fault occurrence at Adani Mundra at Mundra Mohindergarh converter end. The dynamic performance and the interaction between AC and DC system during serious disturbance were researched by case incident data .Generator parameter variation with grid disturbance is shown in graph.

(1) As for the RVO operation of HVDC line transient disturbance occurs frequently that increase loading on AC transmission line. The dynamic interaction between AC and DC system during disturbance is intense.

(2) The exchange power between AC and DC system have a corresponding influence on dynamic performance and control strategies for keeping transient stability .Power exchanging from AC to DC system is advantageous to improve AC system stability.

(3) By proper control, TCSC forced compensation and DC emergent power transfer can improve system stability. Compared with generator tripping and AC/DC separating, they are only a subsidiary control method for the researched system.

(4) Frequency stability by additional DC controls is necessary when AC/DC parallel transmission system changed from connection into separation.

The research will bring importance and significant reference for further operation and stability control of Adani Mundra HVDC and TATA Mundra UMPP AC transmission system. Further research still remained on the topics such as the optimal operation of AC and DC system, DC separated operation and control, strategies design for stability control and so on.

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