Operation in weak grids with HVDC & FACTS devices

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Abstract*: With the advent of HVDC and FACTS devices long distance power transmission has gained momentum in the electrical grid. Distant load centers are being connected to remote generating stations. In this process new elements are being added in the electrical grids to improve the grid stability and facilitate bulk power transmission. Grid stability is the paramount requirement for smooth power transmission. In the present scenario of interconnected ac grid, the charging and tripping of any element in the grid along with any disturbance in any interconnected grid element impacts the entire grid voltage profile significantly. Addition of LCC based HVDC converter station in a weak grid may cause voltage oscillations at certain cases in the connected ac grid. To damp these oscillations STATCOM or SVC may be integrated. Implementation of VSC HVDC in case of any future HVDC power transmission projects needs to be investigated. Also use of STATCOM to black start through LCC HVDC system needs to be explored in a comparatively weaker grid.

***Keywords*: HVDC, FACTS, grid stability, interconnected ac grid, LCC based HVDC, STATCOM, SVC, VSC HVDC, black start.**

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I. INTRODUCTION

LCC based HVDC power transmission technology applies the concept of Reactive Power Compensation (RPC) to meet the reactive power requirement during dc power flow. Generally, the converters in LCC based HVDC system requires reactive power of around 50% - 60% of the ongoing HVDC power. To match the required need of Reactive Power, ac filter sub banks are available in LCC based HVDC system. These filter sub banks provide the reactive power required and they are tuned to different frequencies to eliminate harmonics generated in the system.[1]

When HVDC thyristor converters are connected to weak ac grids, there may be certain problems developing due to overvoltage, sudden voltage fluctuation and issue of voltage instability, harmonics injection, risk arising from commutation failure in the inverter end. Most of these faults are due to the weak ac grid connected to the HVDC poles. Certain means of voltage regulation which can be implemented in weak ac grids are the SVC (Static Var Compensator) and STATCOM (Static Synchronous Compensator). For proper voltage control of the connected ac bus in the HVDC Converter Station, a STATOM or SVC device may be connected to the same bus and HVDC control along with RPC control may be integrated with the STATCOM or SVC control. With SVC / STATCOM connected to the weak ac grid of the HVDC station, the performance of the station will improve in both the dc as well as ac side. In an LCC based HVDC system which is connected to a weak ac grid, voltage oscillations may eventuate in case of any dc power swing momentarily which may lead to connection of ac filter sub banks as per the filter connection schedule based on dc power flow level. The additional filter sub bank may lead to a rise of 4-5 kV in a weak ac grid which is not desirable.

TABLE I: DATA SHOWING THE INSTALLED CAPACITY AVAILABLE AND PEAK DEMAND ACROSS DIFFERENT REGIONS IN INDIA[2][3].

	North Eastern India	**Eastern India**	**Northern India**	**Southern India**	**Western India**
Installed Capacity	4523 MW	33521 MW	99478 MW	111940 MW	120526 MW
Peak demand	2998 MW	22043 MW	50121 MW	41492 MW	50631 MW

From Table 1. It is evident that North eastern region of India (NER) has fewer power generating units and connected elements and also the power demand is quite less in comparison with other regions of India.

North Eastern region of India has fewer lines and elements connected in the electrical grid as compared to the electrical grids of other parts of India. NER has also majority of transmission line trippings due to vegetation growth since the rainfall is quite high in NER compared to other regions. Higher rainfall leads to faster vegetation growth which needs regular clearing at shorter intervals throughout the season.

NER has only 01 no. of HVDC Converter Station which is owned by PGCIL and it is a thyristor based HVDC ±800 kV Converter Station connecting Biswanath Chariali (Assam) to Agra (Uttar Pradesh). As per prevailing grid conditions and load requirement, the above HVDC link is being used for bidirectional power transmission to match the seasonal generation and load variation.

During different types of ac side faults (ph-g, ph – ph, 3ph-g) the voltage oscillation in a weak grid is felt significantly.

Connecting of a STATCOM/SVC device in the existing power system network of the weak grid shall look into the following conditions until the short circuit capacity is increased:

(i) Reduce commutation failure when the weak grid is the inverter in the existing HVDC power transmission corridor.

(ii) Reduce voltage rise extent during sudden load disconnection & fault

(iii) Black start facility.

II. Problem Definition And Simulated Solutions

(i) *Chances of commutation failure when the weak grid is the inverter in the existing HVDC power transmission corridor:*

In a weak ac grid, the trip of sudden HVDC poles may lead to ac voltage rise. HVDC pole trip due to commutation failure needs to be avoided as the weak grid is in constant danger of low ac voltage in case any element trip in grid.

Thyristor based HVDC (LCC-HVDC) system is used in long distance and bulk power evacuation power transmission project. However, it has the problem of commutation failure in the inverter end when connected to a weak ac grid or voltage dip in the connected ac grid. The best possible solution to prevent commutation failure at the inverter end is to regulate the ac bus voltage in the HVDC substation. The ac bus voltage can be controlled by regulating the reactive power required in the substation. One potential solution is the use of Voltage-Source-Converter (VSC) type STATCOM device. [4]

Disturbances in the AC network can cause voltage drops and phase shifts in the voltages. This in turn can cause the voltage-time area to be insufficient, and cause what is called a commutation failure in a LCC based HVDC system. Keeping a large voltage-time area can be difficult hence it also means a lower voltage output as well as a higher current, which in turn increases the converter reactive power consumption. The desire to maintain an adequate voltage-time area while still keeping the reactive power supply requirement and voltage ratings down places tough constraints on the control system. It has been observed that HVDC installations in combination with a weak AC grid have resulted in commutation failures to spread to other links in the area. It is therefore preferable to improve the possibility to detect and react to disturbances that could lead to commutation failure caused by influence of other HVDC transmissions. [5] A lot of research work has already been carried in this field aiming to reduce the impact of commutation failure in the inverter end for LCC based HVDC system. Various techniques have even been studied to eliminate the commutation failure by the implementation of Thyristor Based Controllable Capacitor (TBCC) [6].

Earlier research [7] has been carried out to integrate the STATCOM system on an existing LCC based HVDC system on the inverter end to reduce the impact of commutation failure as shown in Fig.1.

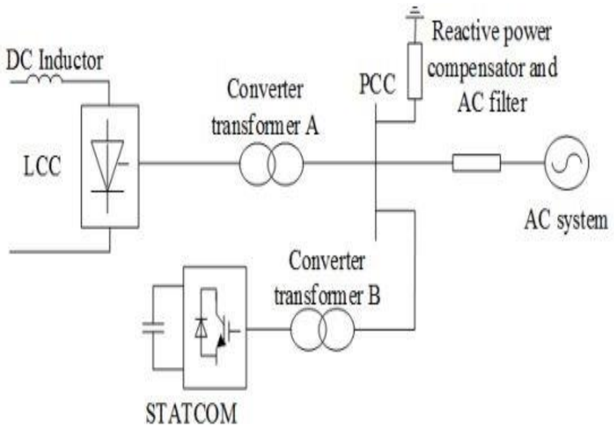


Fig. 1: SLD for integration of STATCOM with LCC HVDC [4]

Commutation failure immunity index (CFII) is the measure of the ability of the system to resist commutation failure. The commutation failure immunity index (CFII) which is a measure of the difficulty and ease of commutation failure, is defined as :

$$CFII = V^2_{ac} / Z_{fault} P_{dc} \qquad (1)$$

P_{dc} represents the DC power (rated), V_{ac} is the rated line voltage and Z_{fault} is commutation failure critical impedance. It is evident from equation (1) that this index is linked to the dc line voltage (rated), DC power (rated) and the commutation failure critical impedance. According to the earlier research [7], the higher is the index value, more is the capability of the inverter to oppose the commutation failure, and lesser is the risk of the commutation failure.

The above research [7] also concluded that in a weak AC grid with short circuit ratio (SCR) of 2.5, 100MVA STATCOM has the capability to reduce the chances of commutation failure, thereby increasing commutation failure immunity and improve the overall stability of the connected ac and dc grid. Therefore, STATCOM can efficiently increase the immunity of HVDC system to commutation failure [7].

Therefore, similar model of STATCOM can be installed along with the existing thyristor based HVDC system to prevent commutation failure in the HVDC system which may lead to Pole outage. Also, the frequent stresses on HVDC system due to sudden dip of ac voltage due to tripping of any element in the weak grid can be avoided.

(ii) Low Short Circuit Ratio of a weak grid

The peak AC voltage at HVDC terminals connected to a weak AC system (SCR=2.5) can reach over *1.47pu* for load rejection, when fixed capacitors provide reactive power. The study [8] shows that using SVC with a TCR dynamic rating of *0.335pu*, the peak AC voltage is limited to *1.16pu*. This also substantially improves stability margin and transient response. Weak AC systems are classified as having SCR (Short Circuit Ratio) 2<SCR<3.

In particular the inverter terminals experience more problems because of an increased risk of commutation failure. An important consideration is that of the overvoltage caused by the fixed reactive power support (for example AC harmonic filters), which can occur for sudden HVDC load rejection. The voltage rise would be transmitted through the system down to the distribution level where a high magnitude overvoltage lasting the duration of the HVDC recovery may not be acceptable. Equally, at the transmission level, such a high overvoltage may cause transformer saturation.
One of the possible solutions to these challenges is to install an SVC (Static Var Compensator) at the HVDC terminals as shown in Fig.2. The primary requirement of the SVC is to provide short term overload reactive power absorption to compensate sufficiently for the AC harmonic filters in order to bring the AC overvoltage to within acceptable limits.

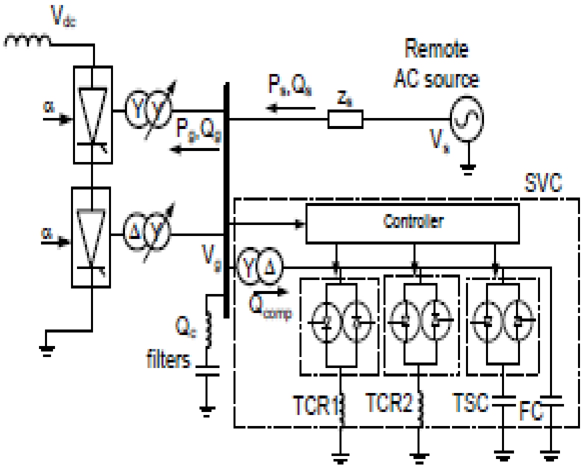


Fig.2: HVDC terminal with SVC [8]

However, having made the decision to invest in the SVC the SVC's steady-state rating can be used to optimize the overall HVDC + SVC reactive power solution further reducing or simplifying the switching arrangements for the shunt connected AC filters/reactive power banks.

Also, connection of a STATCOM in any part of the weak grid can help in preventing sudden voltage fluctuations. Connection of STATCOM in a weak grid has been simulated by using the CIGRE model available in SIMULINK.

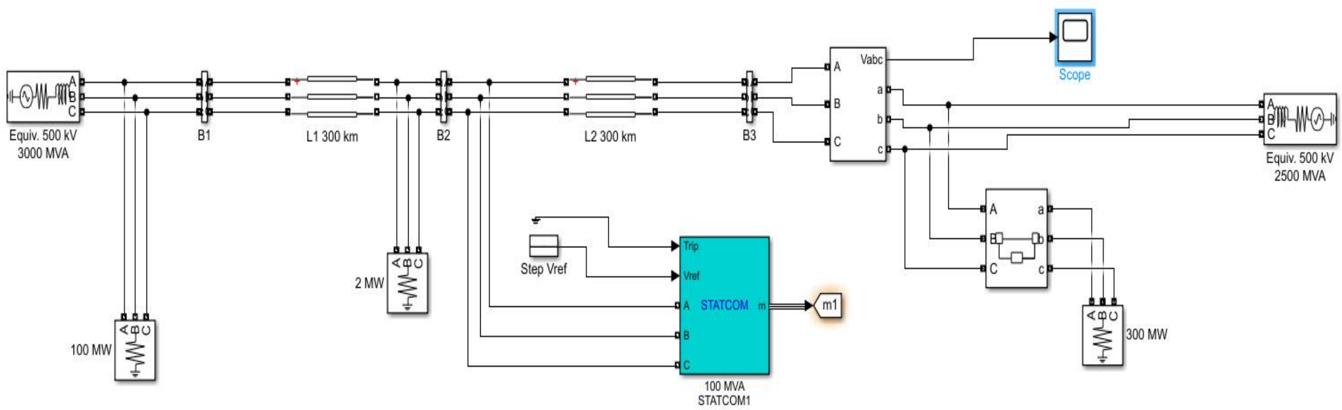


Fig.3: Simulink model for simulation of load disconnection near weaker system [9]

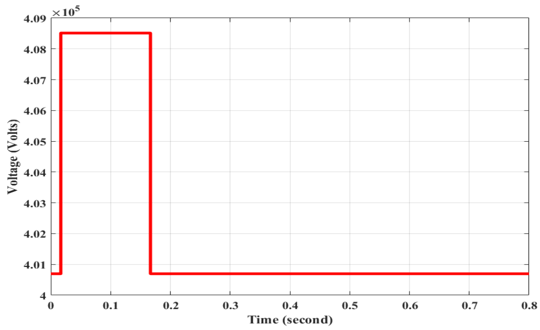


Fig.4: Voltage near to the 2500 MVA system without STATCOM connected to the system.

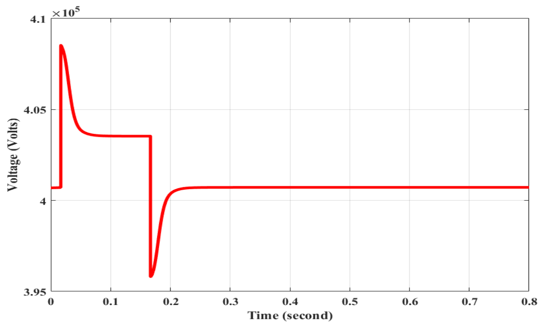


Fig.5: Voltage near to the 2500 MVA system with STATCOM connected to the system.

In Fig. 3, the CIGRE model of system having STATCOM from SIMULINK library has been used to study and simulate the impact of sudden load disconnection with and without STATCOM connected in a weak grid. In this model, a 3000 MVA system is connected to a 2500 MVA system via 300 km long line with a STATCOM device connected in between. The STATCOM is kept in voltage regulation mode. Several loads are connected in the system. The voltage of the bus near the weaker system having 2500 MVA shall be monitored.

In the first case, the 300 MW load connected near the 2500 MVA system is disconnected suddenly without STATCOM in service and reconnected after some duration. The output voltage is shown in Fig.4. In Fig. 4, it can be seen that the voltage rise is sudden and the voltage rise remains constant till the load is reconnected. The voltage rise is not controlled.

In the second case, the 300 MW load connected near the 2500 MVA system in Fig. 3 is disconnected suddenly with STATCOM in service and reconnected after some duration. The output voltage is shown in Fig.5 In Fig.5, it can be seen that the voltage rise is sudden but it is again pulled back to a lower value and it is not allowed to rise till the 300 MW load gets reconnected to the system. The voltage rise is controlled by STATCOM.

Similarly, a 3-ph-ground fault has been simulated in the CIGRE model available in SIMULINK library for STATCOM to study and simulate the impact of a fault with and without STATCOM in a weak grid. In Fig. 6, the CIGRE model of system having STATCOM from SIMULINK library has been used. In this model, a 3000 MVA system is connected to a 2500 MVA system via 300 km long line with a STATCOM device connected in between. The STATCOM is kept in voltage regulation mode. Several loads are connected in the system.

The voltage of the bus near the weaker system having 2500 MVA shall be monitored when a 3-ph ground fault is created near the 3000 MVA system.

In the first case, the 3-ph ground fault ground is created near the 3000 MVA system without STATCOM in service and fault is cleared after some duration. The voltage near the 2500 MVA system is shown below:

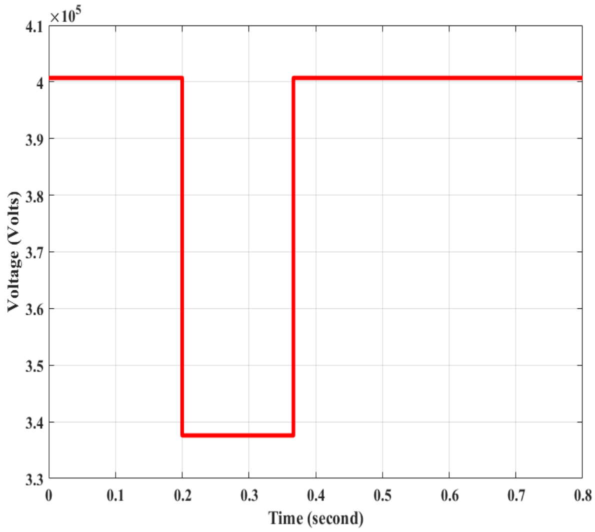


Fig.7: Voltage near to the 2500 MVA system without STATCOM connected to the system

In Fig. 7, a 3 -ph-ground fault has been created near to the 3000 MVA system and the impact of the fault near to the 2500 MVA system is observed without STATCOM connected to the system. It can be seen that the voltage fall is sudden it falls below 340 kV and the voltage remains constant till the fault is cleared. Voltage returns to the normal value after the fault has been cleared.

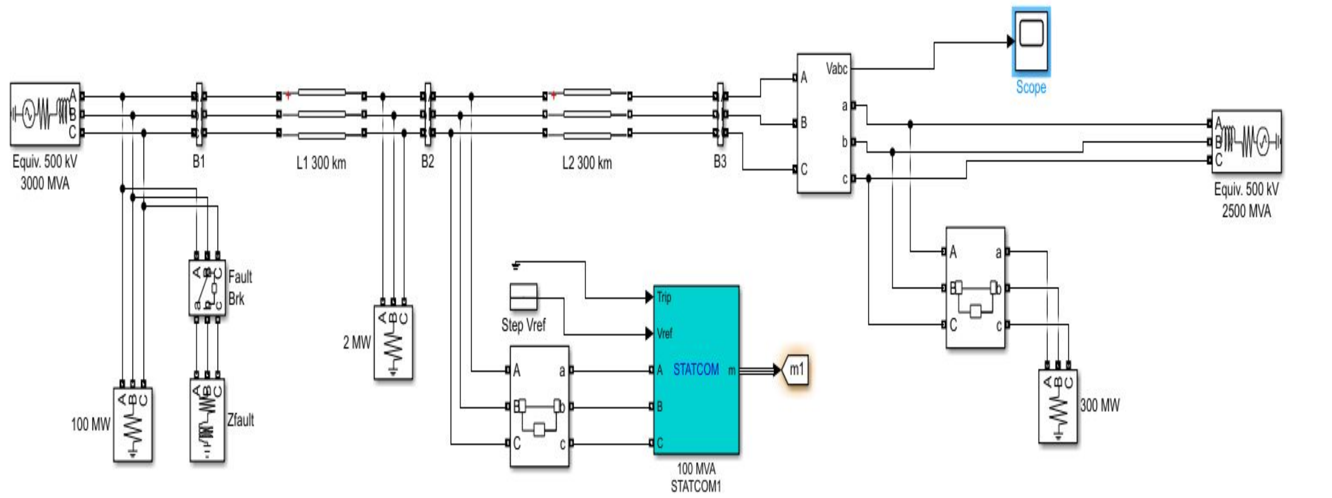


Fig.6: Simulink model for 3-ph fault simulation near bigger system [9]

In the second case, the 3-ph fault is created near the 3000 MVA system with STATCOM in service and fault is cleared after some duration. The voltage near the 2500 MVA system is shown below:

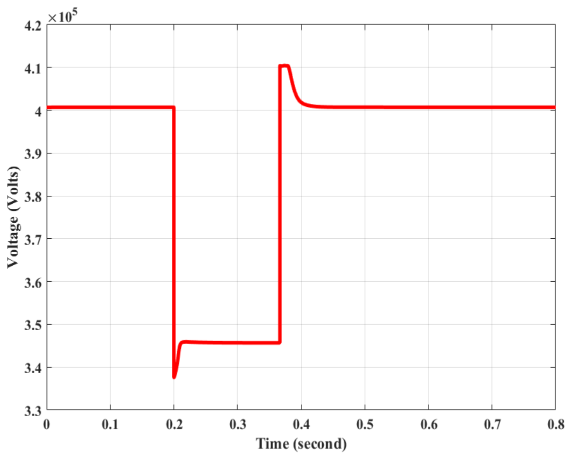


Fig.8: Voltage near to the 2500 MVA system with STATCOM connected to the system

In Fig. 8, it can be seen that the voltage falls below 340 kV momentarily and it is brought back to about 345 kV. The voltage fall is sudden but the voltage fall is recovered immediately due to the STATCOM in service. Also the voltage fall is lesser compared to the system without STATCOM. The voltage is restored immediately the fault is cleared.

From the above cases, it can be concluded that use of STATCOM in a weaker grid shall be beneficial in the following ways:

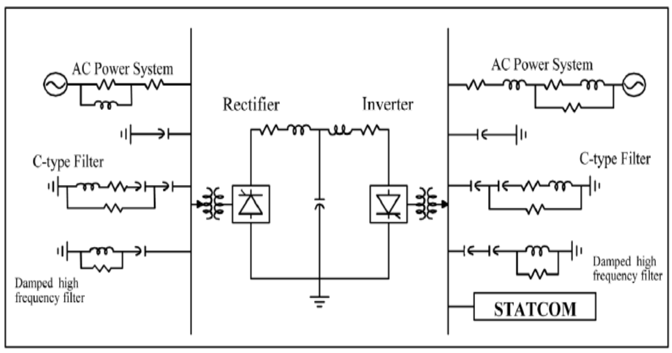
(a) Due to frequent line trippings related to vegetation growth, even the load is disconnected, the voltage rise will be controlled.

(b) In case of fault in other remote connected region, the voltage oscillation is felt significantly in the weak grid which can be controlled with the connection of STATCOM in the weak grid.

(iii) Black start facility:

In an LCC based HVDC system, the converter transformers at both Rectifier and Inverter ends have to be energized to facilitate dc power transmission. In case of grid black out the LCC based HVDC system is not being used in the present power system scenario to black start the ac grid in case of complete grid blackout. However, earlier research [10] has proposed a HVDC – STATCOM system as shown in Fig. 9.

In this research, a STATCOM device has been connected on the Inverter ac bus to control the inverter ac bus voltage to prevent any commutation failure at inverter end and also to provide the additional feature of black start in case the necessity arises. Fig.9 represents the proposed model for a weak grid. The DC capacitor in Fig.9 (Cdc) of the STATCOM is powered up by an auxiliary supply. The auxiliary supply consists of a rectifier "B". The auxiliary supply is powered up by the diesel engine ("C"). The effectiveness of the proposed scheme to inject reactive power into the ac bus when required is affected by the STATCOM's MVA rating. And the capability of the scheme to supply active power depends on the energy storage capacity of the connected DC capacitor.



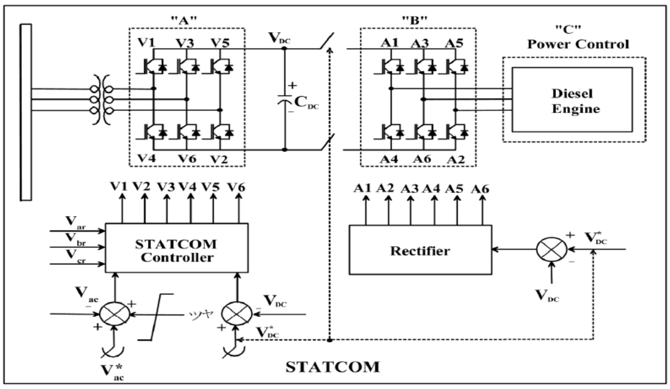


Fig.9: Proposed HVDC STATCOM system in weak grid [10]

In Fig.9, the diesel engine and the connected rectifier are for the process of "black start" of the HVDC substation. In case of complete grid failure black start procedure is required. Before initiating the system after a complete grid failure, disconnection of the load from the HVDC inverter side is required.

In a HVDC station when there is complete ac grid failure, the ac bus will be dead as result of which the connected ICTs will also be dead thereby leading to complete failure of converter transformer and valve cooling fans tripping which shall lead to HVDC pole tripping and complete substation blackout. In this case, the STATCOM is used to supply the required output voltage for ac bus and converter transformers energization of the HVDC system through the small diesel generator and a rectifier. The DC capacitor is powered up by the auxiliary power supply till the dc power flow starts. When the capacitor has been completely charged, the STATCOM output voltage will be able to charge the connected ac bus which shall also energize the HVDC converter transformers for dc power flow.

After the HVDC converters have been deblocked, the auxiliary power supply powering up the the DC capacitor (Cdc) shall be isolated. [10]

LCC based HVDC is generally used as a load to balance the system after power is restored in the islanded grid. However, with the use of STATCOM and diesel engine with rectifier, the LCC based HVDC of the weak grid can be utilized as the first source for grid black start and restoration if the remote grid of the HVDC link is healthy.

(iv) Voltage Control in weak grid by LCC based HVDC system:

In any thyristor based HVDC system, the RPC - Q-control mode connects and disconnects ac filter banks based on the quantity of reactive power consumption of the HVDC Converters as the dc power transmission varies.

However, for a weak grid like if the RPC is put on Voltage Control (V-control) mode with smaller MVAR capacity of the filter sub banks, these sub banks will get connected and disconnected to the ac grid based on the connected ac grid voltage directly. In case of any dip in ac voltage which is dangerous for the inverter station as it may lead to commutation failure, the RPC will connect a filter sub bank directly to boost up the voltage. This will help to regulate ac grid voltage whenever required. The smaller capacity of the filter sub banks will not cause much voltage oscillation whenever it gets connected. However, the total MVAR capacity of the filter sub banks must be adequate to facilitate full load/overload dc power transmission when required.

V-control mode with larger step size of filter sub banks may cause overvoltage in the grid. Step size of filter sub bank is critical especially in weaker grids.

III. CONCLUSION

From the above discussions and simulation works carried out it can be concluded that the problem of sudden prominent voltage oscillation in a weak ac voltage grid is due to comparatively low SCR of the grid. It can be improved if further more transmission lines and elements are connected to the system.

In an LCC based HVDC system, in case of grid blackout the LCC based HVDC technology can be used for black start with the use of STATCOM connected to a diesel engine and a rectifier. This technique can reduce the duration of grid black out and restore the power in the electrical grid quicker.

If any future HVDC project is envisaged connecting a weak grid, it can be VSC based HVDC technology to provide more stability and voltage controllability to the weak grid. In future, with the integration of more transmission lines and hydroelectric projects in NER, the problem of overvoltage in NER shall be solved automatically as the short circuit capacity of the grid shall increase significantly.

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