Some Studies of Measures to Minimize the Negative Effects of Voltage Instability

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***Abstract*— In this paper the design of a controller for a VSC HVDC terminal which is robust over a range of operating points is described. The operating range is first characterized as an uncertainty region around a linear nominal model using the operating points of a non-linear model. A key feature of the HVDC technology in CSC is the ability to precisely control power transfers in accordance with scheduled transactions by those who have purchased rights to its capacity. Additional benefits of the elected HVDC technology.**

***Keywords*— Power system voltage stability ,High voltage DC transmission (HVDC), voltage source converter (VSC).Emergency Power system, Deregulated Power System**

I. Introduction

Power system stability has been recognized as an important part of power system operation since long time. Many major blackouts caused by power system instability have illustrated the importance of this phenomenon. As power systems have evolved through continuing growth in interconnections, use of new technologies and controls, and the increased operation in highly stressed conditions, different forms of system instability have emerged. For example, voltage stability [1], frequency stability and interred oscillations have become greater concerns than in the past. The power system is dependent of a stable and reliable control of active and reactive power to keep its integrity. Loosing this control may lead to a system collapse. Voltage Source Converter transmission system technology such as HVDC [3] has the advantage of being able to almost instantly change its working point within its capability curve. This can be used to support the grid with the best mixture of active and reactive power during stressed conditions.VSC transmission system can

therefore give added support to the grid. In a parallel case where the VSC transmission is connected in parallel with the AC system, the VSC transmission system can damp~2-3 times better than reactive shunt compensation and increase loadability ~1.5 times installed MVA converter size. The benefits with a VSC transmission system during a grid restoration can be considerable since it can control voltage and stabilize frequency when active power is available in the remote end.

II. Categories of Power System Stability:

The classification of power system stability proposed here is based on the following considerations .[1]

- The physical nature of the resulting mode of instability.
- The size of the disturbance considered, which influences the method of calculation and prediction of stability.
- The devices, processes, and the time span that must be taken into consideration in order to assess stability.

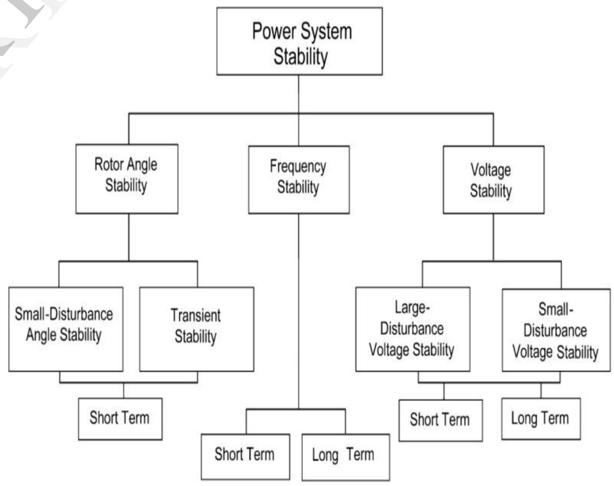


Figure. 1 Classification of power system stability

Figure.1 gives the overall picture of the power system stability problem, identifying its categories and subcategories.

III. Analysis of Power System Voltage Stability:

The characteristics of voltage stability are illustrated by a simple example. Figure 3 shows a simplified two-bus test system. The generator produces active power, which is transferred through a transmission line to the load. The reactive power capability of the generator is infinite; thus the generator terminal voltage V_1 is constant. The transmission line is presented with a reactance (jX). The load is constant power load including active P and reactive Q parts.

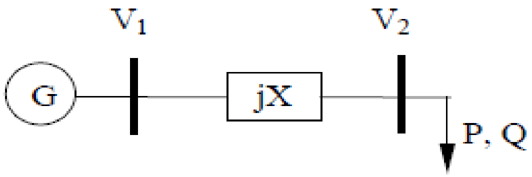
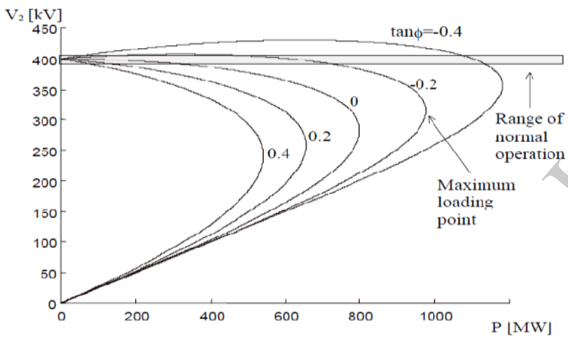


Figure. 3: Two-bus system.

The purpose of the study is to calculate the load voltage V_2 with different values of load. The load voltage can be calculated analytically in this simple example. Generally voltages are solved with a load-flow program. The solution of equation 1 is the load voltage for the load-flow equations of the example, when the voltage angle is eliminated. [2]

$$V_2 = \sqrt{\frac{(V_1^2 + 2QX) \pm \sqrt{V_1^4 - 4QXV_1^2 - 4P^2X^2}}{2}} \;\ldots\ldots\ldots..(1)$$

The power system can only operate in stable equilibrium so that the system dynamics act to restore the state to equilibrium when it is perturbed.



A. Reactive Power Capability of Synchronous Generator:

The voltage dependence of generator reactive power limits is, however, an important aspect in voltage stability studies and should be taken into account in these studies.

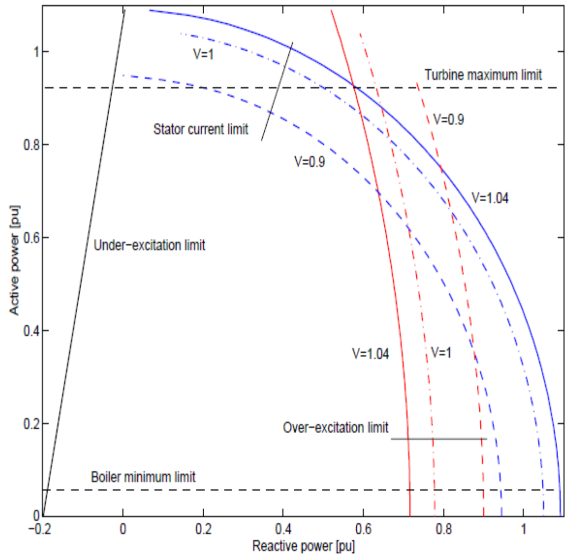


Figure. 5: PQ-diagram (X_d=0.45pu,I_{smax}=1.05pu,E_{max}=1.35pu)

The terminal voltage, the maximum of stator current I_{smax} and the active power of generator P_G determine it.

$$Q_{r\max} = \frac{V^2}{X_d} + \sqrt{\frac{V^2 E_{\max}^2}{X_d^2} - P_G^2} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$Q_{r\max} = \sqrt{V^2 I_{S\max}^2 - P_G^2} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3)$$

B. Automatic voltage control of synchronous generator:

The stator current limits are reached at the reactive power outputs of 0.83, 0.70 and 0.60 pu when output power is 0.5, 0.75 and 0.9 pu respectively.

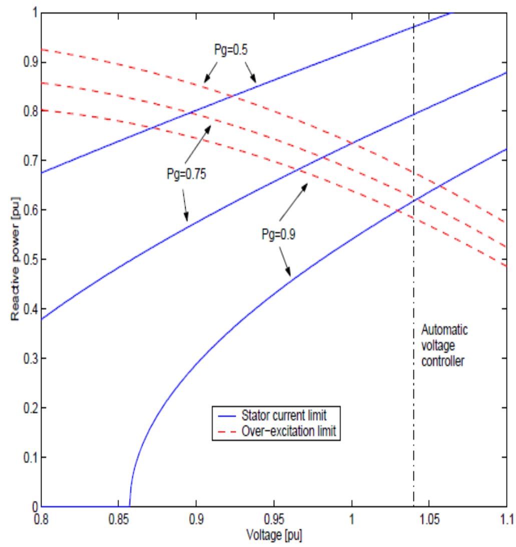


Figure. 6: QU-diagram
(X_d=0.45pu, I_{smax}=1.05pu,E_{max}=1.3

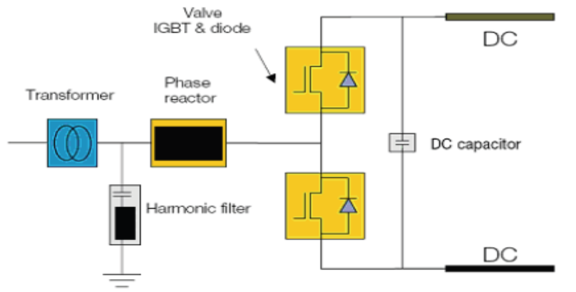
C. Loads:

The modelling of loads is essential in voltage stability analysis [2]. The voltage dependence and dynamics of loads requires consideration in these studies.

$$P = P_{\circ}\left(\frac{V}{V_{\circ}}\right)^{\alpha}, Q = \left(\frac{V}{V_{\circ}}\right)^{\beta} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

IV. Converter Topology:

VSC-HVDC converters [3] include Insulated Gate Bipolar Transmission (IGTB's) and operate with high frequency Pulse Width Modulation (PWM) in order to get high speed control of both active and reactive power, according to Figure 7 and Figure 8. The reactive power in each terminal can even be controlled independent of the dc. [4,5]



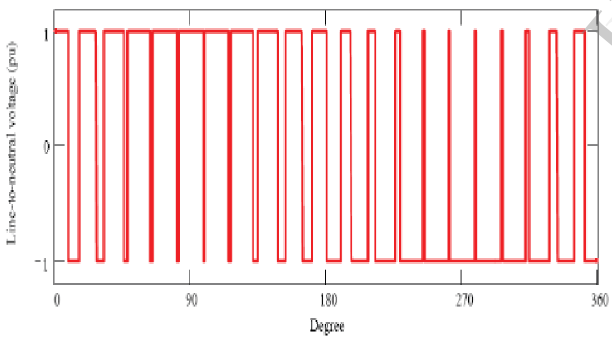


Figure. 8: Single-phase ac voltage output for two-level converter with PWM switching

V. The Capability Curve of a VSC Transmission System:

There are mainly three factors that limit the capability seen from a power system stability perspective.

The first one is the maximum current through the IGBTs. This will give rise to a maximum MVA circle in the power plane where maximum current and actual AC voltage is multiplied. If the AC voltage decreases so will also the MVA capability.

The second limit is the maximum DC voltage level. The reactive power is mainly dependent on the voltage difference between the AC voltage the VSC can generate from the DC voltage and the grid AC voltage. If the grid AC voltage is high the difference between the maximum DC voltage and the AC voltage will be low.

The third limit is the maximum DC current through the cable. The different limits are shown in Figure 9. For a decreasing AC voltage level the maximum DC voltage level will vanish and the maximum current level will decide the capability.

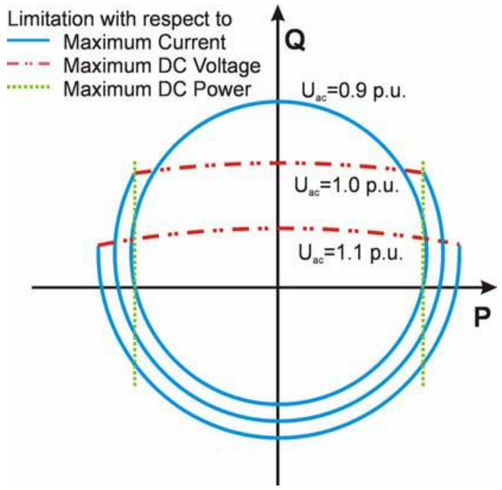


Figure. 9: The capability curve

The small bias in Q-axis direction is due to the line reactor and the filter capacitance within the VSC transmission system [6]. Smaller adjustments in the calculations presented below will therefore be necessary when evaluating the qualitative results of a VSC transmission.

A VSC transmission system can virtually instantly take any working point within the capability chart. Instant active power flow reversals are also possible since the VSC transmission system changes DC current direction and not DC voltage polarity.

VI. Model for Voltage Stability Improvement:

The simple power system shown in Figure.10 is used to study the voltage stability improvement for power systems with VSC-HVDC. The load is exponential voltage dependent load. The active and reactive components of the loads have constant current and constant impedance characteristics, respectively. The losses of the converter stations are assumed to be constant. B_{sh} is a shunt capacitor which helps to keep the voltage U_3 around 1 pu for different load levels. The used VSC-HVDC model in Figure.10 is taken from ABB's HVDC with power rating 373 MVA. The values used can be found in [7].

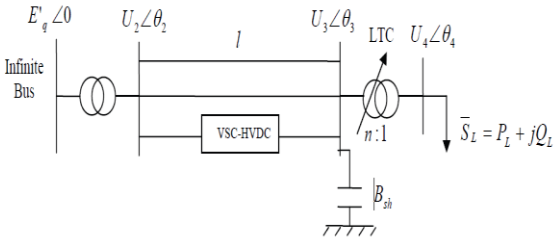


Figure 10: Test Power System model

VII. Result:

After the disturbance has occurred in the test power system the most affected bus in voltage stability is bus 3. Figure.11 shows the voltage at this bus. From this figure it can be observed that increase of active power flow P_{dc} through VSC-HVDC has an improvement in voltage stability compared to original VSC-HVDC and decrease of active power flow through VSC-HVDC. Furthermore, active power flow P_{dc} through VSC-HVDC is shown in Figure.12. Comparing these figures, an increase of 100 MW P_{dc} through VSC-HVDC gives the optimal voltage value (closest to 1 p.u). Observing increase of active power curve in Figure.11for the time > 1200s the voltage drops rapidly, i.e. to an unstable level. Thus, the more increase of active power P_{dc} on the dc link the VSC has less space to generate reactive power and cannot match up the required need of reactive power. Furthermore, in Figure.12 it can be seen that there is a maximum active power P_{dc} transmission through VSC-HVDC for increase of active power through VSC-HVDC which is around 275 MW for this load level.

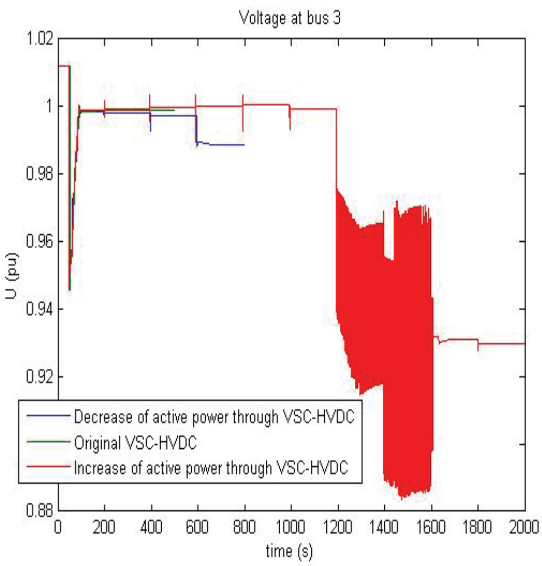


Figure.11: Voltage at bus 3 for increase active power.

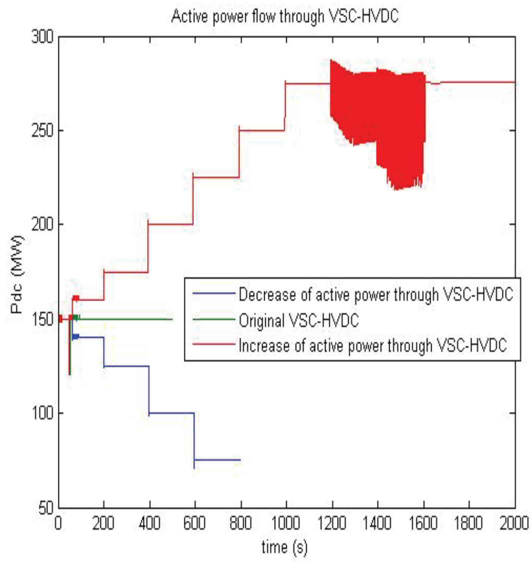


Figure.12: Active power flow through VSC- HVDC.

Studying active power flow P_{dc} through VSC-HVDC which is show in Figure .12 and reactive power injection Q_{inj} into bus 3 which is show in Figure.13, the more increase of active power flow P_{dc} through VSC-HVDC the less reactive power injection into bus 3.

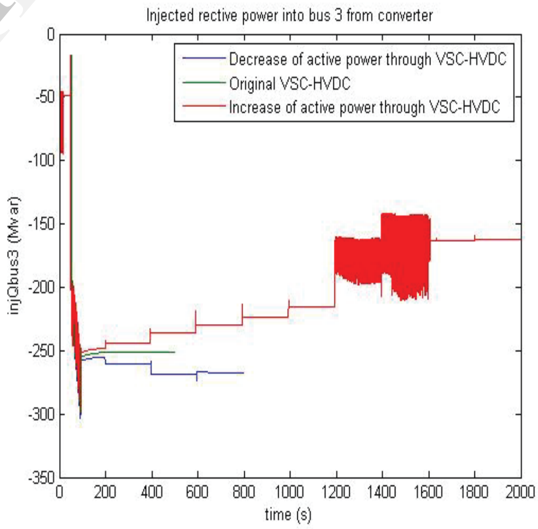


Figure 4.20: Injected reactive power into bus 3 from converter.

VIII. Conclusions:

The goal of to this paper is study to minimize the negative effect of voltage instability and investigate the voltage stability improvement for power systems equipped with VSC-HVDC links by decreasing and increasing active power flow through VSC-HVDC. To clarify the voltage stability improvement a comparison between decrease and increase of active power transmission through VSC-HVDC has been made.

If the VSC-HVDC link is heavily loaded and a disturbance occurs in the power system, a decrease of dc power allows the VSC-HVDC to support the voltage.. Since the disturbance decreases the voltage at faulty bus there is a need of reactive power injection into this bus to increase the voltage.

- Decrease of active power flow through VSC-HVDC improves the voltage stability, since decrease of dc power allows the injection more reactive power into the bus and support the voltage.
- If the dc link is lightly loaded and a disturbance occurs in the power system, an increase of dc power allows the VSC-HVDC to support the voltage.
- The increase of active power flow through VSC-HVD gives the best voltage level (close to 1 pu).
- If the ac link is heavily loaded increase of active power transfer through the VSC-HVDC gives an improvement in voltage,

because an increase of active power through VSC-HVDC decreases reactive power need in the ac lines and thereby less reactive power compensation by the VSC-HVDC is needed.

IX. FUTURE WORK:

This paper proposed active power control through VSC-HVDC to improve voltage stability on power systems. According to the results achieved, it would be of great interest to study following subjects in future:

- Same investigation could be made on a complex power system, for example, on the well known in reference [8].
- Build a controller which automatically could reduce active power flow through VSC-HVDC.
- Make investigation for more disturbances.
- The chattering behaviour should be investigated since the LTC or VSC or both might cause the chattering.

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