ALTERNATIVE WAYS TO ENHANCE PERFORMANCE OF BTB HVDC SYSTEMS DURING POWER DISTURBANCES

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ABSTRACT- **This paper proposes two controllers to mitigate the DC link voltage oscillations in HVDC systems during power disturbances. The comprehensive analytical design procedure is represented for both the controllers. The effectiveness of the controllers are verified and evaluated through simulation.**

***Key words* — BTB HVDC system, BackStepping Controller and Integrator Factor Controller.**

1. INTRODUCTION

As the global population continues to grow, resources are becoming even more stretched.Growing population need more land as well as adequate electrical and communication services and these must be provided in a way that complies with the enviornmental regulations. A power system depends on stable and reliable control of active and reactive power to keep its integrity.Losing this control may lead to a system collapse.

High Voltage Direct Current transmission is an economical way for long distance transmission or interconnection of asynchronous systems with different fequencies. It is desirable to have the high power electronics based systems available during different power system faults. If the protection measures trip the converter system it takes several fraction of an hour depending on the size of the converter to discharge the DC link and check the healthiness of the whole system. Hence several practical methods have been proposed and implemented to keep the system alive by suppressing mainly the huge currents that the semiconductor switches supply during fault. These fault currents are generated mainly due to inherent delay effect of switching on how the controller observes the disturbances. In addition the overvoltages that can occur during fault may exceed the switching forward/reverse blocking capability. Some of the valuable control structures for VSC based Back to Back HVDC systems have been proposed based on a set of standard Proportional Integral controllers, but DC link voltage control has been found as the main difficulty. The oscillatory nature of the DC link voltage cannot be vanished with any of the controllers. The other drawback is that the DC link dynamics will be observable to the load side. So these are the major drawbacks in HVDC systems during power disturbances.Two controllers are proposed to damp the DC link voltage oscillations and also to balance the load side voltages.

2. VSC MODELING

The Voltage Source Converter (VSC) modelling is done to obtain the state space equation with which the controller can be designed.The implementation of VSC in HVDC transmission for conversion of three phase AC to DC,permit continous and independant control of real and reactive power and also provide dynamic voltage regulation. The figure below shows the schematic representation of voltage source converter model.

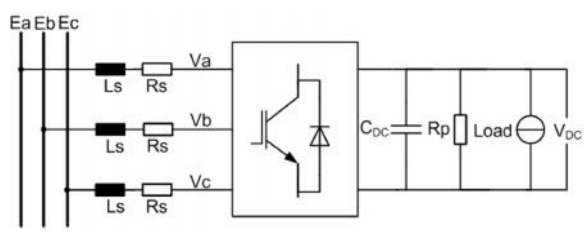

Fig. 1 Voltage sourced converter model

In figure1, E_{abc} is the three phase source voltage, L_s is the source inductance, R_s is the source resistance, V_{abc} is the input voltage to the converter, C_{DC} is the DC link capacitor, R_p is the loss resistor and V_{DC} the dc voltage obtained after rectification. By applying kirchoffs voltage law to the model the expression for inductor current is obtained as shown in equation1 and the expression for capacitor voltage is obtained as equation2.

$$\frac{dI_{abc}}{dt} = -\frac{R_s}{L_s} I_{abc} + \frac{E_{abc}}{L_s} - \frac{V_{abc}}{L_s} \qquad (1)$$

$$\frac{dV_{DC}}{dX} = -\frac{I_{DC}}{C_{DC}} I_{abc} + \frac{V_{DC}}{R_p.C_{DC}} - \frac{I_{load}}{C_{DC}} \qquad (2)$$

To make benefit of all decoupling and constant properties of two phase system compared to the three phase, the inductor current and capacitor voltage is converted to dq reference frame, and the former and later can be obtained as equations 3 and 4.

$$\frac{dI_d}{dt} = -\frac{R_s}{L_s} I_d + W I_q + \frac{E_d}{L_g} - \frac{V_d}{L_s} \qquad (3)$$

$$\frac{dI_q}{dt} = -\frac{R_s}{L_s} I_q - W I_q + \frac{E_q}{L_s} - \frac{V_q}{L_s} \qquad (4)$$

By applying power balance to the model, an equation for the DC link voltage can be obtained as in equation5.

$$\frac{dV_{DC}^2}{dt} = 3\frac{E_d I_d}{C_{DC}} - 2\frac{V_{DC}^2}{R_p C_{DC}} - \frac{P_{load}}{C_{DC}} \qquad (5)$$

The general form of state space equation is shown in equation6, where X(t) is the state variable vector, U(t) is the input vector and e(t) is the disturbance vector,

$$X(t) = AX(t) + BU(t) + Ke(t) \qquad (6)$$

$$X(t)\begin{bmatrix} I_d \\ I_q \\ V_{DC}^2 \end{bmatrix} U(t) = \begin{bmatrix} V_d \\ V_q \end{bmatrix} e(t) = \begin{bmatrix} E_d \\ E_q \\ P_{load} \end{bmatrix}$$

Here the losses in the interface tansformer is neglected, E_q is also considered as zero since E_a is aligned with d axis in the synchronous frame. Hence the state space equations of the system taking d and q components of current and DC link voltage as the state variables can be represented by equations 7,8 and 9.

$$\dot{x}_1(t) = a_1x_1 + a_2x_2 + a_3e_1 + a_4u_1(t) \qquad (7)$$

$$\dot{x}_2(t) = -a_2x_1 + a_1x_2 + a_3e_2 + a_4u_2(t) \qquad (8)$$

$$\dot{x}_3(t) = a_5e_1x_1 + a_6x_3 + a_7e_3 \qquad (9)$$

In the above equations the values a_1 to a_7 can be obtained by performing calculations with the system parameters.

3. CONTROLLER DESIGN

During power system disturbances the DC link voltage drops, but it should be maintained at a constant value inorder that the desired power transfer takes place through the transmission line. The paper discusses two controllers to maintain DC link voltage at required level.

A. Integrator Factor Controller(IFC)

In IFC we select the input to the modulator in order to get the desired response, which is to maintain the DC link voltage.Firstly the controller is designed for $I_q(x_2)$ dynamics. The objective for I_q controller is to have a decoupled and disturbance rejection characteristics. This criteria is obtained if its input U_2 has the form of equation10. The first term in this equation is responsible for the response time of the state and the rest is for decoupling, disturbance rejection and command following.

$$U_2(t) = -f_2X_2 + \frac{a_2}{a_4}X_1 - \frac{a_3}{a_4}e_2 + t_2X_{2ref} \qquad (10)$$

Secondly the controller is designed for the first state variable X_1. Here also the objective is to have a decoupled and disturbance rejection characteristics, however, this state is controlled to maintain the required dynamics for X_3 also as X_3 does not access to a direct input to control the state directly. Hence, the input for X_1 should have the form as in equation11.

$$U_1(t) = W_1(t) - f_1X_1 + \frac{a_2}{a_4}X_2 - \frac{a_3e_1}{a_4} \qquad (11)$$

To create an input as well as cancel out the non linearity of x_3 it is assumed

$$X_1(t) = e_1(t) - \quad (t) \qquad (12)$$

The value of $x_1(t)$ can be calculated from the above equations as equation13.

$$x_1(t) = x_1(t_0)e^{(a_1-a_4f_1)} + e^{(a_1-a_4f_1)}\int_{t_0}^{t} e^{(a_1-a_4f_1)2} a_4 w_1(T)\, d2 \qquad (13)$$

The required value of new input which can control the DC link voltage is then calculated as equation14.

$$W_1(t) = \frac{(t)}{a_4e_1(t)} - \frac{(t)}{a_4}\left(\frac{u_1 - u_4f_1}{e_1(t)} + \frac{e_1(t)}{e_1^2(t)}\right) \qquad (14)$$

With the help of new control input $W_1(t)$ state X_3 can be controlled directly, and the expression for X_3 can be written as equation 15 and the new control input is given in equation 16.

$$\dot{x}_3 = a_5 \quad (t) + a_6x_3 + a_7e_3 \qquad (15)$$

$$(t) = f_3x_3 - \frac{a_7e_3}{a_5} + t_3x_{3ref} \qquad (16)$$

Figure 2 shows the block diagram of integrator factor control which is used to generate switching signals to the converter.

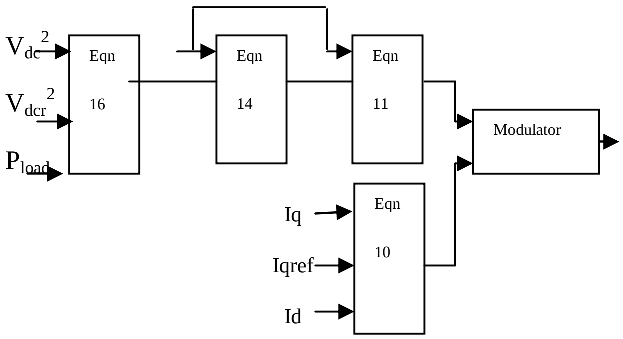

Fig 2 Integrator factor control model

The state now has a virtual input which can control the state directly. Among many possibilities of input choice a typical form of input signal is selected to control the response time, disturbance rejection and command following.

B. Back Stepping Controller(BSC)

In BSC control signals are designed for nonlinear systems by a recursive technique in which we can design feedback controls and finds Lyapunov functions for a set of n increasingly complex systems, the last system being of interest.The fundamental of the idea can be interpreted as the local control of the states that do not access to a direct input. Here, some states are used as a pseudo control to stabilize other states by introducing some virtual state variables representing the difference between the actual and virtual control. In this case the second state variable can be controlled directly and so the system reduces to a two state system.
The change of the coordinates to Z in equation17 indicates that X_1 should take whatever value to make the error Z_1 in equation18 null corresponding to achieve the reference Z_3.

$$Z_3 = X_3 \quad (17)$$
$$z_1 = x_1 - \alpha(z_3, e_3) \quad (18)$$

The virtual control is chosen as in equation19 to meet the requirement viz choosing the correct Lyapunov function and making their derivatives zero, thereby controlling the third state variable which is the DC link voltage. Hence the input signal is chosen as$W_1(t)$ as in equation20.

$$\alpha(Z_3, e_3) = -f_3 Z_3 - \frac{a_7}{a_8} e_3 \quad (19)$$

$$W_1(t) = -\frac{f_1}{a_4} z_1 - \frac{a_1}{a_4} z_1 - \frac{a_1 \alpha(z_3, e_3)}{a_4} + \frac{\alpha(z_3, e_3)}{a_4} \quad (20)$$

The values of f_1 and f_3 are selected so as to obtain the required input to the modulator.The constraint is that the mode associated with Z_1 should be faster than that of Z_3 where Z_1 and Z_3 have the nature of the current and DC link voltage respectively, and hence the controller follows the well known rule in power electronics to design the current controller faster than the voltage one.

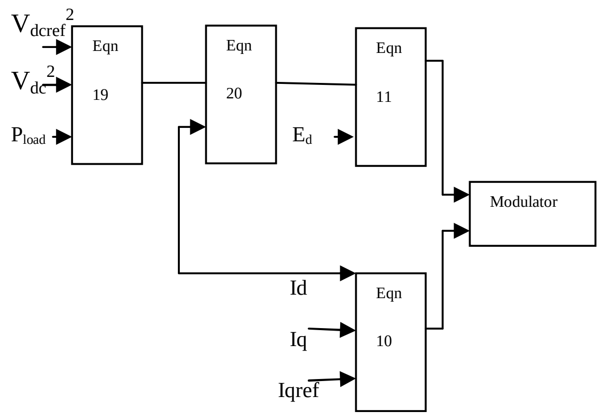

Fig 3 Back Stepping Control model

4. PERFORMANCE OF PROPOSED CONTROLLERS

The system performance under different fault conditions are studied with parameters as shown in table 1.

Line to line voltage	110V
Leakage inductance	0.36mH
DC link voltage	250V
Loss resistor	154Ω
Line frequency	60Hz

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Table 1. Simulation parameters

An HVDC system is modeled with the above parameters and the DC link voltage of the system is obtained as shown in figure4. Then the system is subjected to a single phase to ground fault and a three phase fault then the DC link voltage is seen to drop. Then the controllers are implemented to provide switching signals to the converters and performance is studied through simulation. The performance of the controllers is identical and the oscillations do not appear in the prescence of proposed controllers.The phase compensation is a major contribition of the proposed controllers to suppress the DC link voltage oscillations.

5. RESULTS AND DISCUSSION

The HVDC system under different fault conditions are observed to check the feasibility of the proposed controllers.

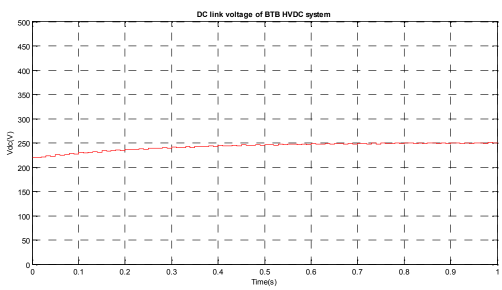

Fig 4 DC link voltage of the system

1.Single phase to ground fault

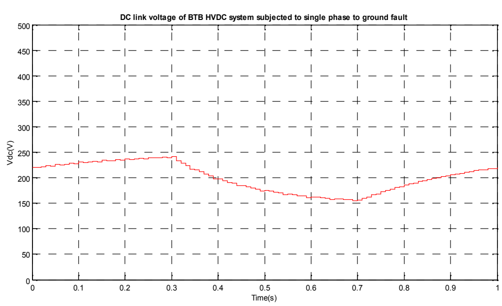

Fig5 DC link voltage under single phase to ground fault

When the HVDC system is subjected to a single phase to ground fault the fall in DC link voltage is unavoidable which is shown in figure5. When the controllers are implemented the DC link voltage is maintained at the required value, which is shown figure 6. Also it can be seen that the states dynamic variations for the change in command are identical for both controllers. The performance improvement is obvious with the controllers.

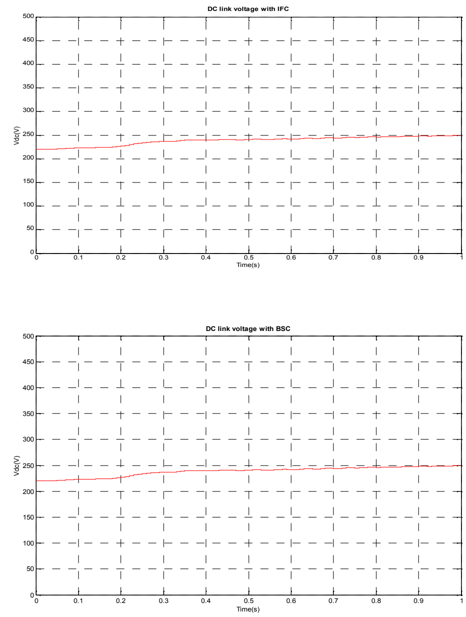

Fig6 Effect of controllers on DC link voltage under single phase to ground fault

2. Three phase fault

When the HVDC system is subjected to a three phase fault,there is a much severe fall in DC link voltage as shown in figure7.

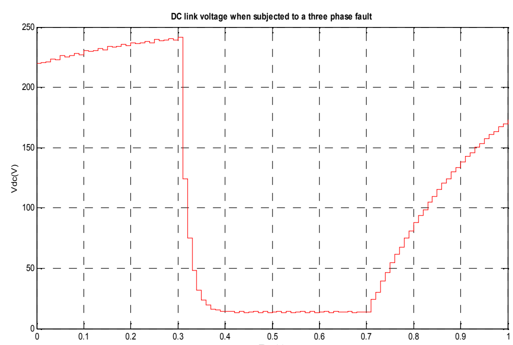

Fig7 DC link voltage under three phase fault

In the case of most severe case of a three phase fault also the effectiveness of the controllers can be seen in mitigating the drop in DC link voltage as in figure 8.

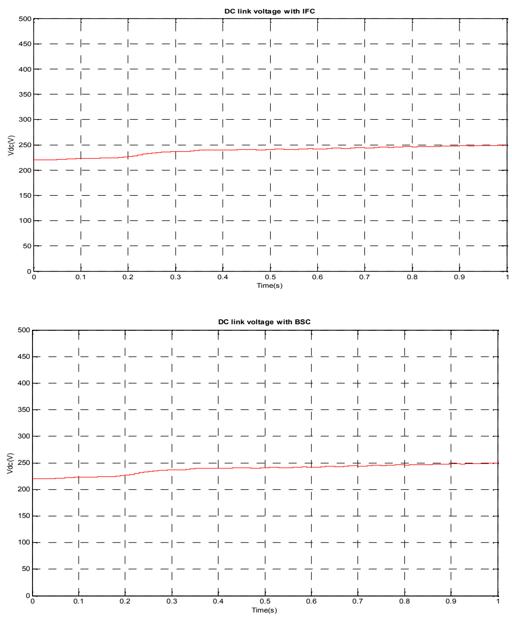

Fig 8 Effect of controllers on DC link voltage subjected to three phase

3. Effect on load dynamics

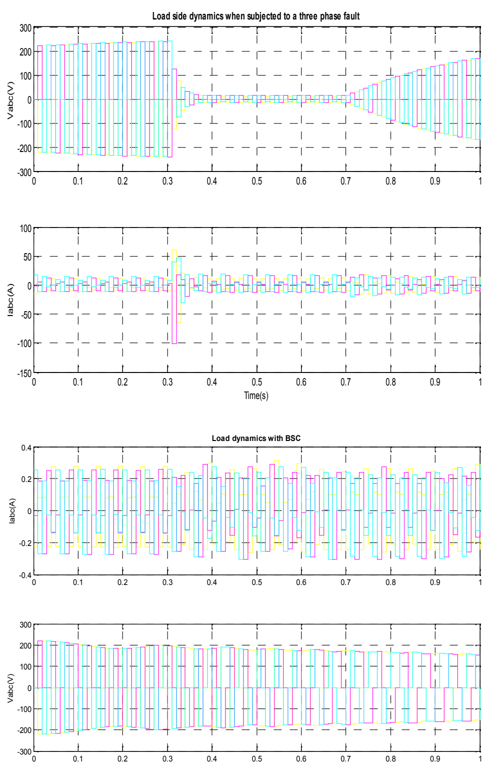

Fig 9 Comparison of load side dynamics without and with the controllers during a single phase toground fault.

It can be seen that there are distortions in load side voltage and current during both single phase to ground fault as well as a three phase fault as shown in figure9. With the implementation of the controllers IFC and BSC in the system, the distortions in the load side is also effectively reduced. The simulation results proves the effectiveness of the controllers in maintaining the DC link voltage and thereby reducing distortions in the load side voltage. The effect of both the controllers is identical in maintaining DC link voltage and load side dynamics.

6. CONCLUSION

The paper proposes alternative ways of enhancing the performance of an HVDC system. The HVDC system is modeled and is subjeced to fault conditions, the resulting oscillations in DC link voltage and the effect on load side dynamics are damped with the controllers which is proved by simulation in MATLAB. Thus maintaining the DC link voltage, effective transmission of real power is made possible through the HVDC system.It has been proved analytically that the implementation of the proposed controllers has enhanced the performance of the VSC based HVDC system when subjected to power system disturbances in the inverter side.

7. REFERENCES

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APPENDIX

The parameters for IFC are:

$$f_1 = \frac{\lambda_i + a_1}{a_4}$$
$$f_2 = \frac{\lambda_c + a_1}{a_4}$$
$$f_3 = \frac{\lambda_c + a_6}{a_5}$$
$$t_2 = -\frac{a_1 - a_4 f_2}{a_4}$$
$$t_3 = -\frac{a_6 - a_5 f_3}{a_5}$$

The parameters for BSC are:

$$f_1 = \lambda_i$$
$$f_2 = \frac{\lambda_i + a_1}{a_4}$$
$$f_3 = \frac{\lambda_c + a_6}{a_8}$$
$$t_2 = -\frac{a_1 - a_4 f_2}{a_4}$$
$$t_3 = -\frac{a_6 - a_8 f_3}{a_8}$$

The values a_1 to a_7 can be obtained from yhe equations given below

$$a_1 = -\frac{R_s}{L_s}$$
$$a_2 = \omega$$
$$a_3 = \frac{1}{L_s}$$
$$a_4 = -\frac{1}{L_s}$$
$$a_5 = \frac{3}{C_{DC}}$$
$$a_6 = \frac{2}{R_p C_{DC}}$$
$$a_7 = -\frac{2}{C_{DC}}$$

By substituting the values from system parameters the values a_1 to a_7 can be calculated and are made use of in the controller design.