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VSC HVDC IMPLEMENTATION USING HYBRID SIMULATION

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Abstract : **The main aim of this project is a fuzzy controlled LLC HVDC system with AC voltage and reactive power control. This paper has investigated and demonstrated the reactive power and voltage control capability of LCC HVDC system with controllable capacitors. The reactive power control and voltage control at the inverter side of the fuzzy controlled LCC HVDC system with controllable capacitors have been proposed and associated controllers have been implemented. In connection with the reactive power control or voltage control, active power control at the rectifier side is desirable and such a control has been adopted in this paper. This paper investigates the reactive power and AC voltage fuzzy control at the inverter side of the LCC HVDC system with controllable capacitors. The traditional PI controller in the AC voltage and reactive power control is replaced with fuzzy controller improving the response time of the controller and the converter. The modelling of the proposed fuzzy controlled HVDC system is done in MATLAB software with Sim-power-system toolbox generating graphs using GUI environment.**

IndexTerms - **Line commutated converter (LCC), High voltage direct current (HVDC), Reactive power control, Fuzzy controller**.

I. INTRODUCTION

In current years, the stability of power systems and energy usage has stepped forward using a high-voltage DC (HVDC) energy transmission approach. Since high-voltage AC (HVAC) has shortcomings related to high transmission loss, the development of HVDC modeling and control methods can be employed in the power transmission system to enhance the entire power system stability [2]. The advancements in power electronics (PE) interfaced devices incorporated into energy systems support the HVDC system with regard to efficient operations and control [4]. The modeling of a PE-interfaced HVDC system decreases the modeling complexity and computational burden in simulations. Moreover, HVDC is a regularly used technique containing lots of huge-scale power system components [2]. The traditional line-commutated converter high-voltage direct current (LCC-HVDC) transmission structures are broadly utilized in the energy transmission because of the benefits of having the asynchronous AC grid link and the ability of bulk energy transmission over an extended distance [4].

The various control schemes of VSC-HVDC and LCC-HVDC structures on small-sign durability are explored in [5]. In line with that, the performance of control techniques of VSC-HVDC is enhanced with multi-objective optimization [7]. The control techniques on the inverter station of the LCC-HVDC system along with the effects of a phase-locked loop (PLL) on small-signal stability are studied in [19]. The VSC-HVDC system, with the impact of different reactive power control techniques on a small signal, is analyzed [20]. It is reported that the stability of P-Vac command-based VSC-HVDC illustrates high stability under vulnerable AC grids in comparison to the P-Q control when reactive power is adjusted so that it will hold the preferred voltage [21]. A more recent unique and encouraging technique is the dynamic phasor model, which includes facts controllers and HVDC transmission structures.

VSCs can rapidly control the active power exchange by controlling the phase angle of the produced voltage as well as control the reactive power at each terminal by controlling the magnitude of VSC voltage independent of the Direct current power transmission. Due to this property VSCs can be installed anywhere in the AC grid irrespective of the short circuit current capacity. Moreover to change the direction of the power flow in its DC link, VSC does not need to reverse the voltage polarity. This power reversal is observed by changing the direction of the current. Many attempts have already been made to conceptualize the formation of the meshed grids using classic HVDC or CSC technology. However due to the high amount of complexity involved the projects was thereby limited to a maximum of 3 nodes [1]. On the other hand the VSC-HVDC provides the most suitable conditions for a multi terminal system which is the basis for the modeling of a super grid because the number of nodes and the kind of grid topology utilized does not have any limit in the case of VSC-HVDC.

Power Control strategies for VSC- HVDC systems have been widely implemented in literature. [2-5] gives a lucid description of PID based control strategy implemented in the dq reference frame. However the adequate mathematical modeling and thus obtaining the transfer function for the conventional controller design such as the PID controller is difficult for HVDC systems as it consists of nonlinear power electronics devices. Several other modern control techniques such as the Fuzzy Control Strategy and $H-\infty$ based robust control strategy have been applied for this particular problem. The Fuzzy Logic Control strategy has been shown to provide significant improvement over the closed loop response of the VSC-HVDC systems [6-7]. Although an improvement is obtained, the performance is precariously affected because of the dependence on Fuzzy Logic membership function that are applied to tune the PI parameters. In this paper a novel Fuzzy Logic Control strategy is employed for VSC-HVDC to reduce the effect of the accuracy of the Fuzzy Logic membership functions.

II. MODELLING OF VSC HVDC

The need to understand the underlying structure of the VSC station model arises because of the presence of several VSC stations in the VSC based MTDC systems. Figure 1 shows the elements constituting a VSC station. The model consists of AC buses, series reactance, AC filters, coupling transformers and converter blocks on the AC side, and the DC bus, the DC filter and the DC line on the DC side. A single line represents the DC side of the model.

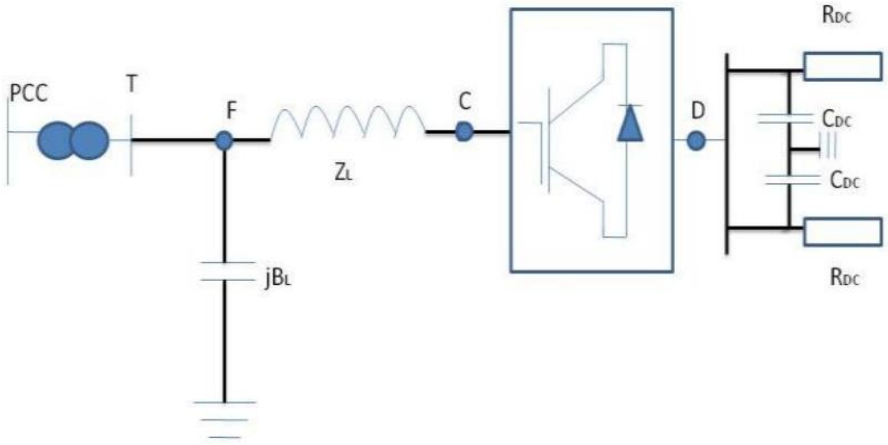


Fig. 1: Schematic of a Two Terminal VSC-HVDC

The point of common connection acts as a medium from where the VSC station is connected to the AC grid. The PCC is connected to the AC side of the VSC through a converter transformer, shunt filter and a phase reactor while as on the other side the DC bus, at which a shunt DC capacitor is connected to the ground, is connected to the DC line on one side and the VSC on the other side

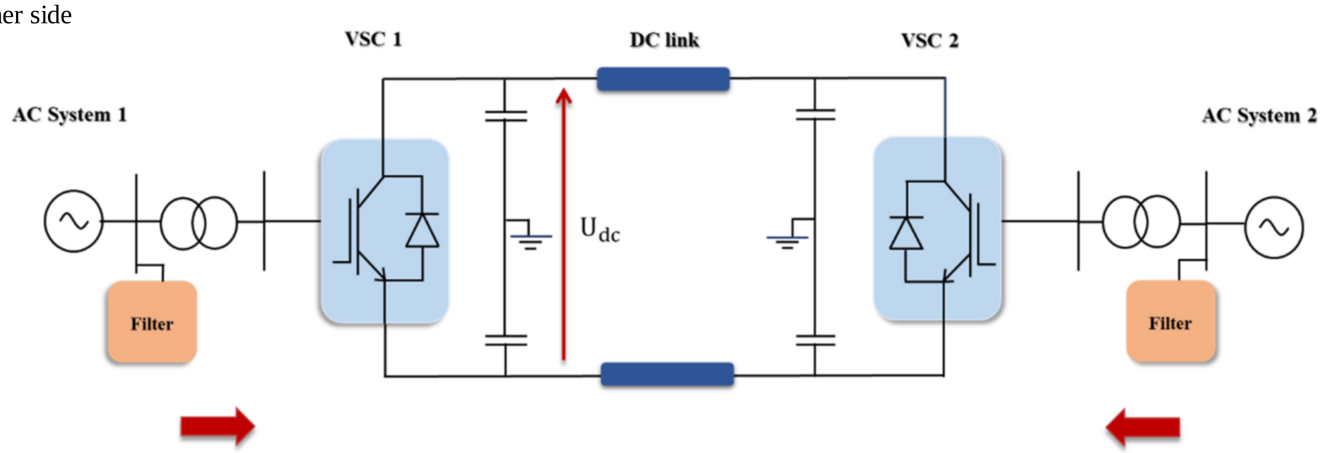


Fig. 2: VSC HVDC station modeling

Two interconnected stations in a VSC-HVDC have symmetry and thus either converter can be used for modeling. In the d-q frame the AC-DC converter can be modeled from Figure 2 as:

$$L\frac{di_d}{dx} = -Ri_d + wLi_q + us_d - u_{cd}$$

$$L\frac{di_q}{dx} = -Ri_q + wLi_d + us_q - u_{cq}$$

$$C\frac{du_{dc}}{dx} = i_{dl} - i_{dc}$$

Where, id, iq and usd, are the dq- axis components of current and voltage of the AC source respectively, and uc ,q are the dq-axis components of AC voltage injected into the converter, R and L are the equivalent resistance and inductance, w is the source frequency, udc is the DC bus voltage, C being the capacitance of the DC capacitor, and idc is the DC bus current.

Using Parks transformation or the Clarkes transformation the dq-axis is aligned so that the d-axis is in phase with the AC source voltage, i.e., usd=us, usq=0. The power exchanges from the AC source to the DC link assuming the losses of the converter and the transformer to be zero is given by:

$$Q = -3u_{sd}i_q/2$$

$$P = 3u_{sd}i_d/2$$

According to the equations, if usd is maintained constant, then P is only proportional to id and Q is proportional to iq. Thus by controlling of id and iq technically termed as a direct current control method active and reactive power can be adjusted and a good dynamic response is possible.

III. Controller Design

FLC-based Direct Power Control

In this section, for the new PVMT and DPC-based VSI model presented in (20), a robust and simple controller consisting of feedforward and feedback control structure is designed. In Figure 2, the FLDPC method's schematic for the PV-VSI is depicted. In this control, the power (real and reactive) references are tracked by controlling their actual value using FLC.

The real and reactive power errors can be obtained using (21):

$$e_P := P_{ref} - P$$

$$e_Q := Q_{ref} - Q$$

where active and reactive power references are represented by P_{ref} and Q_{ref}, respectively, and real and reactive power errors are e_P and e_Q, respectively.

As shown in **Figure** 3, for obtaining zero steady state error, two error signals (e_P and e_Q) and their rate of change (*P-error_rate* and *Q-error_rate*) are given as inputs to two FLCs. The outputs of FLCs provided the control inputs F_P and F_Q for the feed-forward controllers. Due to non-availability of the FLC block in the RSCAD library, FLC is built in RSCAD software by writing codes using ANSI language in C-builder. Each FLC consisted of two inputs and one output, as depicted in Figure 3. The two inputs were the error and error-rates of power for each FLC. The membership functions of inputs and outputs were named identical for both real and reactive power. The variables representing error were NM (negative medium), ZV (zero value), and PM (positive medium). Similarly, error-rate variables were NM1 (negative medium 1), ZV1 (zero value 1), and PM1 (positive medium 1). The variables of output were BNE (big negative error), NME (negative medium error), ZE (zero error) and PME (positive medium error). In **Figure4**, the real and reactive power FLCs membership functions for error, error-rate and outputs are shown. To ensure smooth control by FLC, triangular-based membership functions were considered in this study.

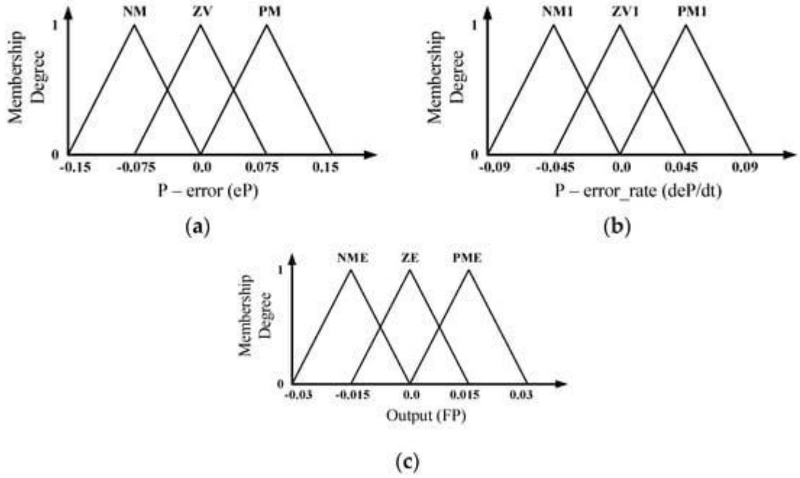


Figure 3. Membership functions of (**a**) P-error (e_P), (**b**) error_rate of P (de_P/dt) and (**c**) output of FLC (F_P).

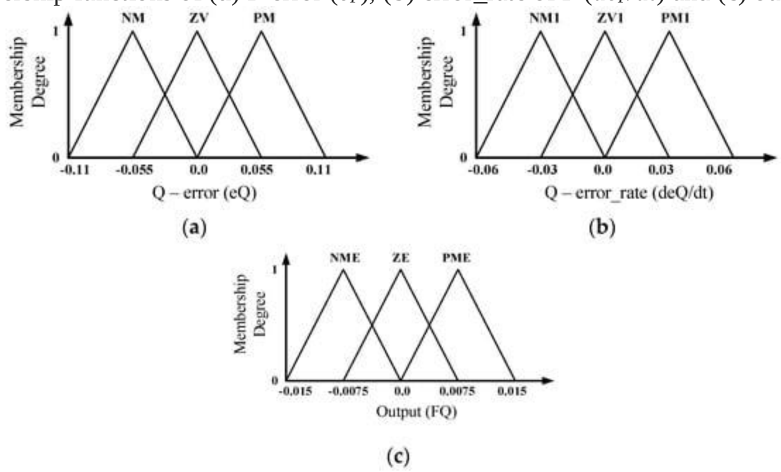


Figure 4. Membership functions of (**a**) Q-error (e_Q), (**b**) error_rate of Q (de_Q/dt) and (**c**) output of FLC (F_Q).

An important part in the design of FLC is choosing the scaling factors of input and output membership functions optimally. This can be obtained by implementing optimization techniques to minimize the deviation between inverter output powers and the reference powers. In this study, a black-box optimization technique known as the nonlinear Simplex method of Nelder and Mead is adopted for obtaining the optimal scaling factors of input and out membership functions. The reason for choosing the black-box optimization technique is that it can be easily used in conjunction with time-domain or real-time simulation tools. The process of black-box optimization entails the successive evaluation of the objective function for the different sets of parameters for the membership functions. In this process, the real-time simulation program, i.e., RSCAD/RTDS, is used to evaluate the value of the objective function. First, an initial set of parameters was used to initialize the real-time simulation in RTDS, and the value of the objective function was numerically evaluated. Then, based on the optimization algorithm and the value of the objective function, a new set of parameters were obtained, and the process was repeated until an optimal set of parameters is determined.

To assign the input and output control, fuzzy rules were formed based on IF-THEN rules, which are summarized in Table 1. The rules were decided depending on the cooperation between the estimated error and complexity of FLC. In this paper, defuzzification was carried out by using the Sugeno-type weighted average method [43] to produce the real crisp output of F_P and F_Q.

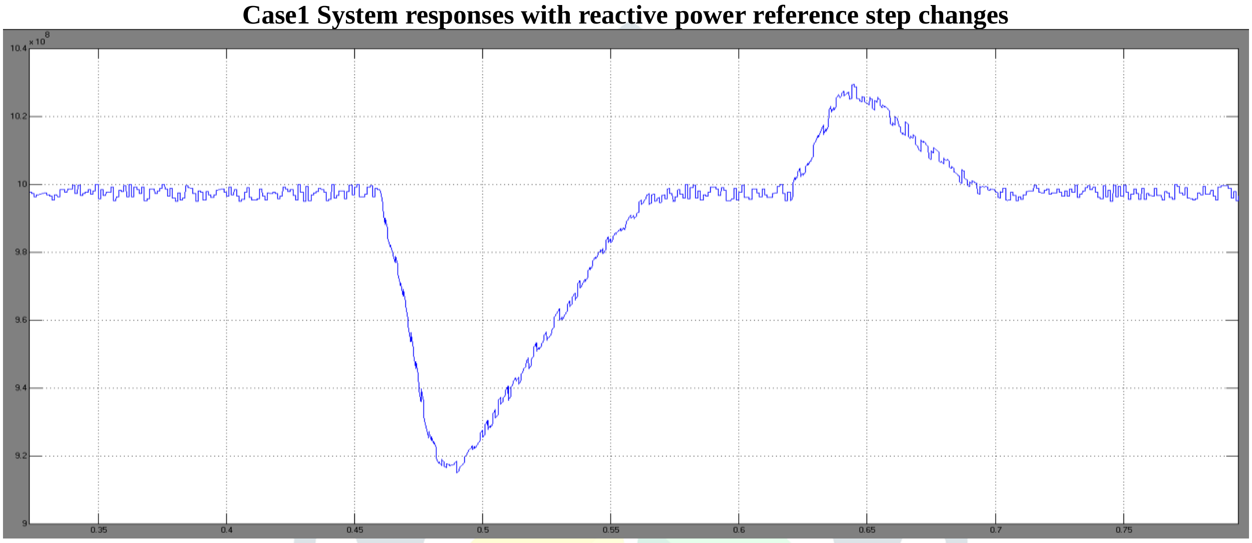
Table 1. Rule table for FLCs of real and reactive power.

Membership Functions		ERROR RATE		
		NM1	**ZV1**	**PM1**
ERROR	**NM**	NME	NME	ZE
	ZV	NME	ZE	PME
	PM	ZE	PME	PME

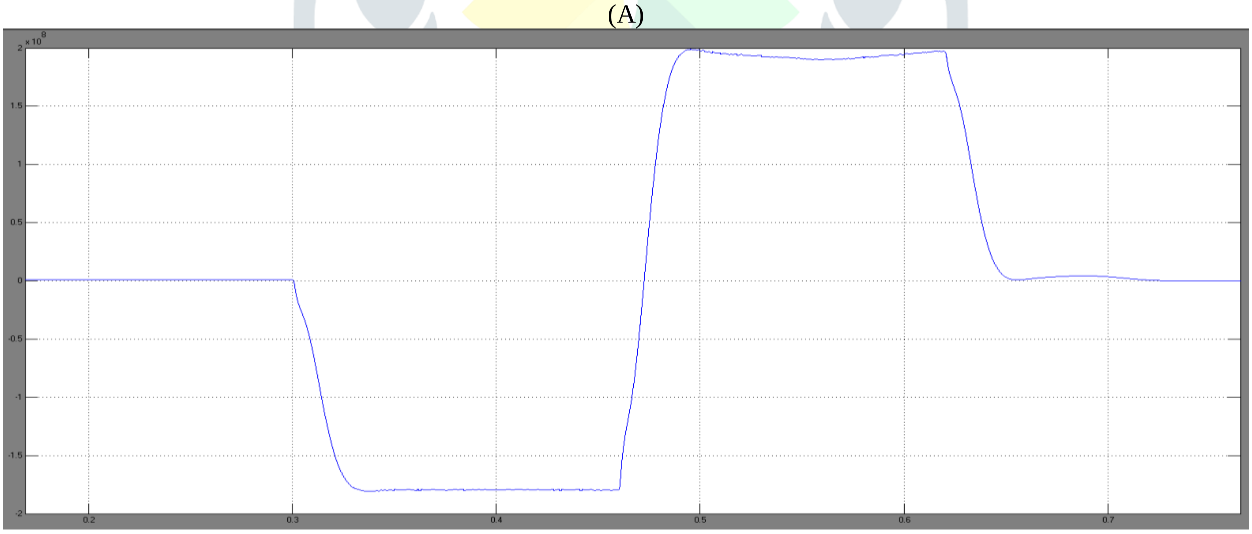
IV. SIMULATION RESULTS

RESULTS WITH FUZZY CONTROLLER

Case1 System responses with reactive power reference step changes

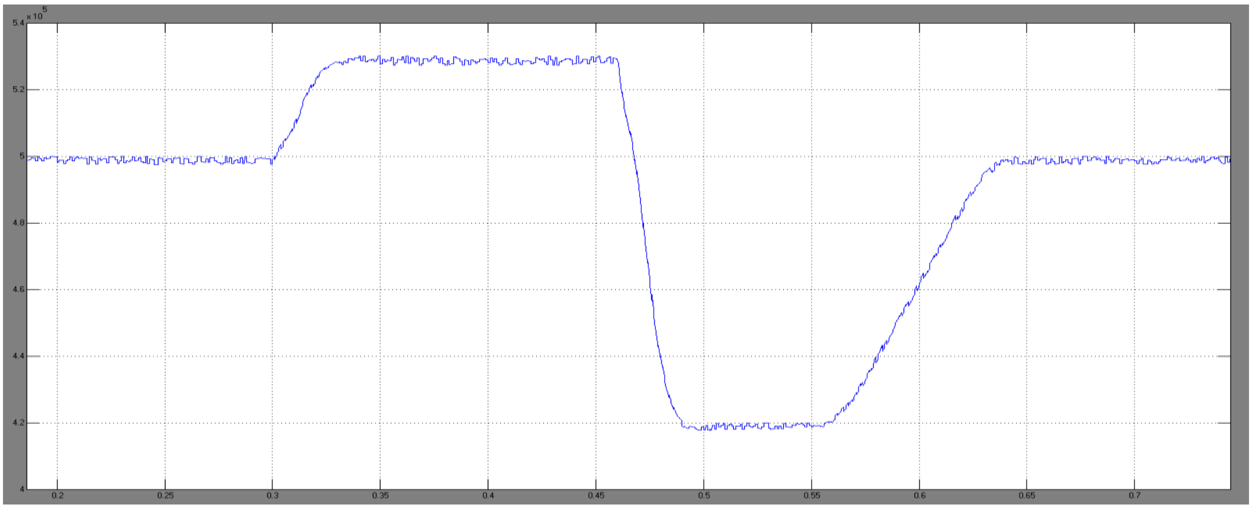


(A)

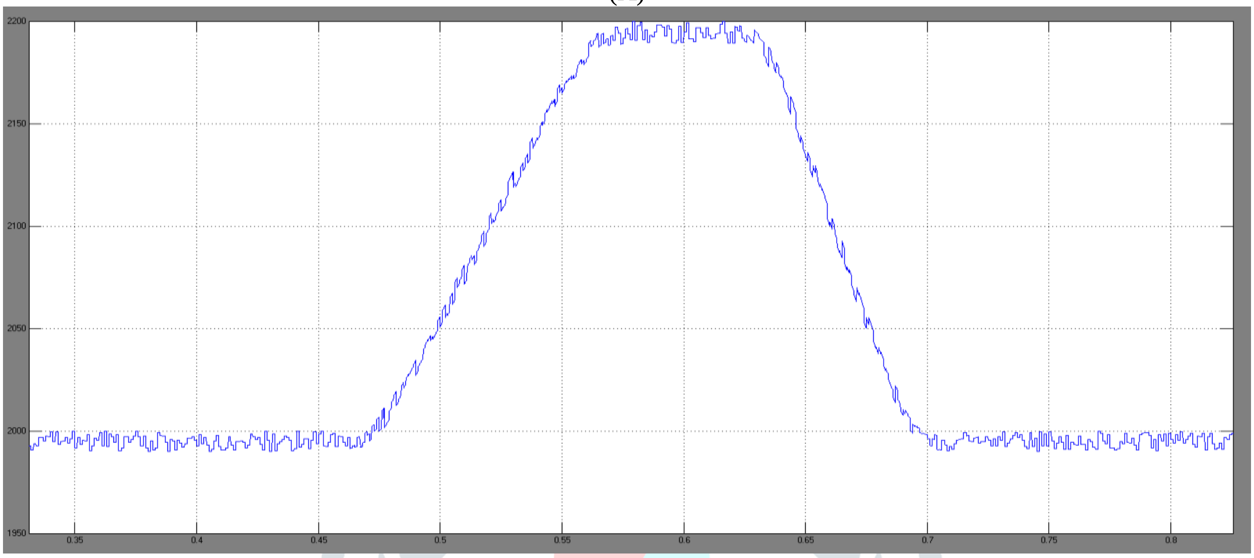


(B)

Fig 5 (A) Active power transfer and (B) Reactive power consumption at inverter



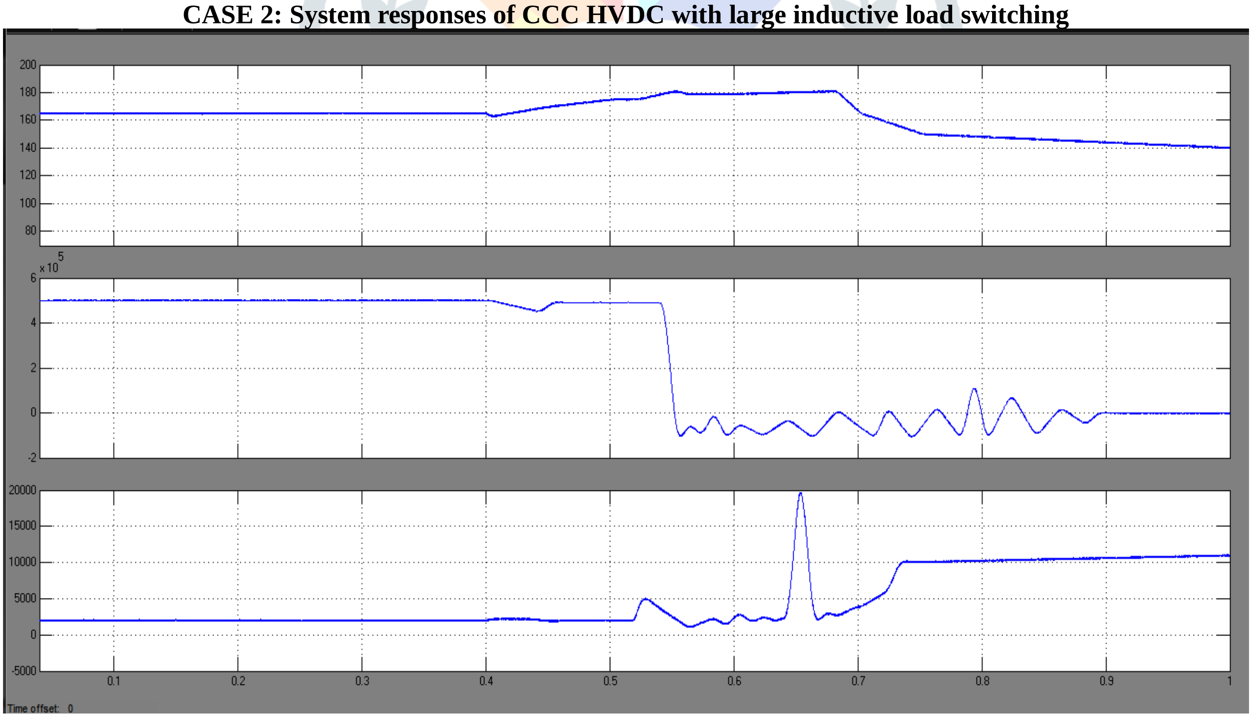
(A)



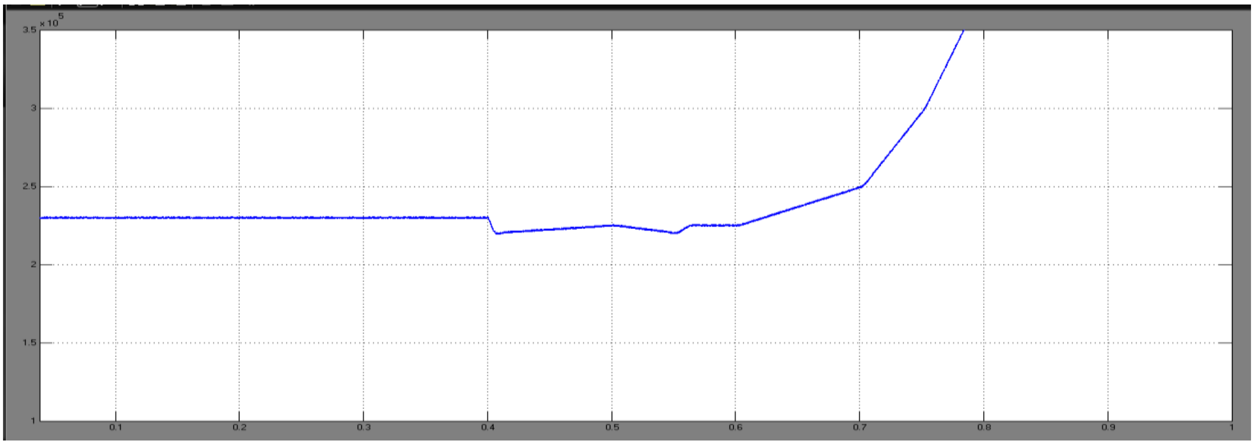
(B)

Fig 6 (A) DC voltage and (B) DC current

CASE 2: System responses of CCC HVDC with large inductive load switching



(A)



(B)

Fig 7 Firing angle, DC voltage and DC current (B) AC voltage

CONCLUSION

This paper has investigated and demonstrated the reactive power and voltage control capability of LCC HVDC system with controllable capacitors. The reactive power control and voltage control at the inverter side of the LCC HVDC system with controllable capacitors have been proposed and associated controllers have been implemented. In connection with the reactive power control or voltage control, active power control at the rectifier side is desirable and such a control has been adopted in this paper. Detailed mathematical analysis has been carried out and it indicated that if the capacitor voltage level is appropriately chosen, the system is able to achieve zero steady-state reactive power consumption. Hence the size of capacitor banks can be significantly reduced, which leads to considerable cost savings. To further exploit the reactive power controllability, the AC voltage controller is designed to control the inverter AC voltage by the converter itself. Simulation studies and comparisons with CCC HVDC and LCC HVDC with SVC have been carried out using RTDS, and verified the HVDC systems effective reactive power and voltage control capability using the approach proposed. The system's ability of operating under negative extinction angle has been utilized to achieve a wide range of reactive power control and, in particular, the ability of exporting reactive power to the AC system. In extension observed by replacing Fuzzy controller it improves the system accuracy shown by simulation.

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