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A FUZZY CONTROLLED LCC HVDC SYSTEM WITH AC VOLTAGE AND REACTIVE POWER CONTROL

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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 Simpowersystem toolbox generating graphs using GUI environment.*

Key words: Line commutated converter (LCC), High voltage direct current (HVDC), Reactive power control, Fuzzy controller

I.INTRODUCTION

In a line commutated converter, the commutation is carried out by the ac system voltage. This brings inherent difficulty in continuing reliable commutation at very weak ac system voltages, e.g., during ac system faults. An ac system is considered to be very weak if the ratio of [short-circuit power at the point of connection] to the [rating of the HVDC scheme] is less than 2. Some HVDC schemes without dc lines operate successfully with a ratio of less than 1.5. In recent years converter topologies using series capacitors in the HVDC converter have also been utilized to overcome some of these problems. Furthermore, the increase in reactive power consumption with the increase of dc power transferred must be taken into account in the design of the scheme and its control system. The line commutated converter based HVDC (LCC HVDC) will continue to be used for bulk power HVDC transmission over several hundred MW, because this mature technology provides efficient, reliable and cost effective power transmission for many applications. The reactive power requirement originates from the firing of thyristors after commutation voltage becomes positive, which in effect delayed the current waveforms with respect to the voltage waveforms [1]. So both rectifier and inverter sides of the system absorb reactive power. However it should be noted that to the sending end AC system, the rectifier represents a load and it is natural that it draws some reactive power from the network just like other loads. On the other hand, from the point of view of the receiving end AC system, the inverter acts as a power producer and as such should take its share of reactive load. But the reality is that instead of producing, the inverter consumes reactive power thus its consumption level of reactive power should be minimized. Furthermore, with passive reactive power compensation at the inverter side, the level of reactive power being produced tends to decrease under transient AC voltage drops where reactive power support is needed most. At the same time, the minimum extinction angle controller will advance its firing angle which leads to a higher reactive power consumption and causes further AC voltage drops. These operational characteristics are clearly unfavorable, and FACTS devices such as STATCOM and SVC, etc may be needed to mitigate the problem. In contrast to what has been described above, the desired inverter performances are Very low or zero reactive power consumption level at steady-state and AC voltage control by inverter itself especially under large AC disturbances. It should be pointed out that the reactive power or voltage controllability at the inverter side should not be achieved at the expense of reduced active power transfer level, as the primary role of an HVDC link is to provide a stable active power transfer.

In this way, the advantage of the inverter reactive power control can be maximized.

II. LCC HVDC SYSTEM

The LCC HVDC system with controllable capacitors [22] and the connected AC system at the inverter side are shown in Fig. 1.LCC HVDC was introduced in the USSR in 1950 (Kashira-Moscow) and in Sweden in 1954 (Gotland). Both systems used mercury arc valves. The first application of thyristor valves was to the Eel River scheme in Canada in 1972. The use of thyristors initiated a rapid increase in the installed capacity of HVDC systems because of the superior reliability of thyristor technology. In recent years further reliability improvements and compact designs with large capacity thyristors (up to 8.5 kV, 4 kA) have contributed to the significant progress of HVDC applications. LCC HVDC has been applied to the following types of power transmission: • Submarine and underground cable transmission • Asynchronous link between ac systems • Long distance bulk power transmission using overhead lines Its technical capability, combined with its economic advantage and low operating losses, make LCC HVDC a practical solution for enlarging or enhancing power system interconnections. This appendix provides an overview of LCC HVDC systems, including the general circuit configuration, control schemes, and operational characteristics. A list of LCC HVDC schemes in operation appears at the end of the appendix.

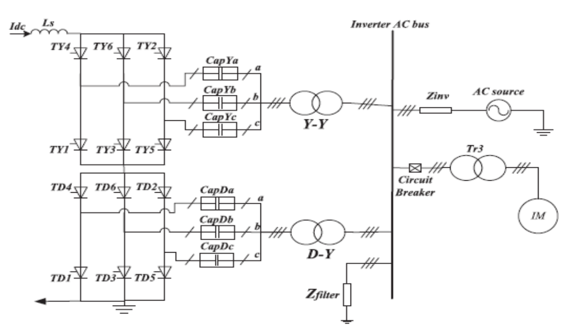

Figure 1. Configuration of LCC HVDC

III. SYSTEM ARCHITECTURE

HVDC transmission systems can be configured in many ways to suit operational requirements. The simplest configuration is the back-to-back interconnection in which two converters are on the same site without a transmission line. Monopolar HVDC is a link using a single high-voltage conductor line and the earth (or the sea) or a metallic low-voltage conductor as a return conductor. In recent schemes the use of earth return is becoming less common because of environmental opposition.The most common configuration is the bipolar link. Figure 2 illustrates a simplified single-line diagram of a two-terminal bipolar HVDC transmission system. With a metallic return, the earth grounding is made at only one terminal A few existing schemes have a multi-terminal configuration in which dc transmission lines connect three or more terminals at different sites. Some LCC HVDC schemes have also been provided with the capability of operating parallel converters at the ends of a dc transmission line.

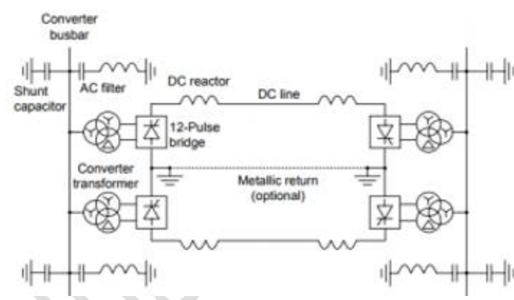

Fig 2: One-line diagram of a two-terminal HVDC system

A) Converters

The converter performs the energy conversion between ac and dc. It usually has a 12-pulse arrangement, in which two 6-pulse bridges are connected in series on the dc side, as depicted in Figure 5. The switching of the valves is ordered by the converter control. The rectifier is the converter in which power flows from ac to dc, and the inverter is the converter in which power flows from dc to ac. The principle of conversion and the waveforms associated with these conversions are detailed in references 4 and 5.

B) Converter Transformers

The converter transformers adjust the supplied ac voltage to the valve bridges to suit the rated dc voltage. The transformer for a 12-pulse bridge has a star-star-delta three-winding configuration, or a combination of transformers in star-star and star-delta connections. The converter transformers may be provided as singlephase or three-phase units. The converter transformer typically has a leakage reactance of about 10-18% to limit the current during a short-circuit fault of the bridge arm.

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C) Harmonic Filters

Converter operation generates harmonic currents and voltages on the ac and dc sides, respectively. On the ac side, a converter with a pulse number of p generates characteristic harmonics having the order of np±1 (n=1,2,3,…). AC filters are installed to absorb those harmonic components and to reduce voltage distortion below a required threshold. Tuned filters and high pass filters are used as ac filters. On the dc side, the order of harmonics is np. DC filters, along with dc reactors, reduce the harmonics flowing out into the dc line. DC filters are not required in cable transmission or back-to-back schemes.

D) Shunt Capacitors

A line commutated converter in steady-state operation consumes reactive power of about 60% of the active, or dc, power transferred. The shunt capacitors installed at the converter ac bus supply the reactive power required to maintain the converter ac bus voltage. To achieve satisfactory power factor for the LCC HVDC converter, the shunt capacitors are normally subdivided and switched by circuit breakers as the dc power varies. Some or all of the shunt capacitors are normally configured as ac harmonic filters.

E) DC Reactors

The dc reactor contributes to the smoothing of the dc current and provides harmonic voltage reduction in the dc line. The dc reactor also contributes to the limitation of the crest current during a short-circuit fault on the dc line. It should be noted that the inductance of the converter transformer also contributes significantly to these functions.

IV.PROPOSED REACTIVE AC VOLTAGE CONTROLLER

Fig. 4 shows the proposed reactive power controller at inverter side where Q_{ref} , Q_{meas} and Q_{error} are reactive power reference, measurement and error signals, respectively; γ_{order} , γ_{meas} and γ_{error} are extinction angle order, measurement and error, respectively; *CE* is the inverter current error signal and αinv is the inverter firing angle. It can be seen that extinction angle reference is generated by minimizing the reactive power error by a fuzzy controller. The proposed inverter controller is shown in Fig. 3 where V_{ref} and V_{meas} are inverter AC voltage reference and measured values, respectively. As can be seen from Fig. 3, a FUZZY controller is used to generate inverter firing angle by minimizing AC voltage error

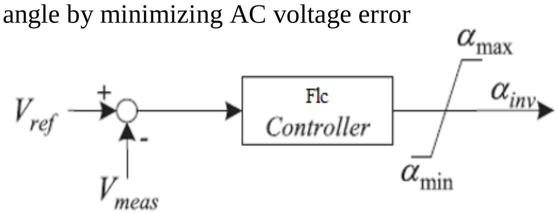


Fig 3. Proposed Inverter AC voltage controller

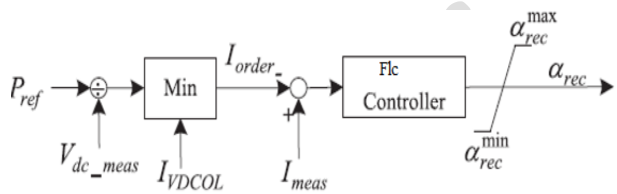


Fig 4. Rectifier active power controller

V. FUZZY LOGIC CONTROLLER

Fuzzy logic is an innovative technology that enhances conventional system design with engineering expertise. Using fuzzy logic, we can circumvent the need for rigorous mathematical modeling A human operator is far more successful in controlling a process than a controller designed by modern analytical technique. So it is worth simulating the control strategy based upon intuition and experience and can be considered as heuristic decision or rule of thumb decision. In academic and technological arena, Fuzzy is a technical term that deals with ambiguity or vagueness based on human intuitions.

During the past several years, FLC has emerged as one of the most active area of research for the application of fuzzy set theory. A fuzzy set is a generalization of the concept of an ordinary set in which the membership function (MF) values can be only one of the two values, 0 and 1. A fuzzy set can be defined as below.

Fuzzy set A in a universe of discourse U is characterized by a MF μ_A: U $\rightarrow$ [0] [1] and associates with each element x of U a number μ_A (x) in the interval [0 1] representing the degree of membership of x in A.

Fuzzy Controller Model

Fuzzy modeling is the method of describing the characteristics of a system using fuzzy inference rules. The method has a distinguishing feature in that it can express linguistically complex non-linear system. It is however, very hand to identify the rules and tune the membership functions of the reasoning. Fuzzy Controllers are normally built with fuzzy rules. These fuzzy rules are obtained either from domain experts or by observing the people who are currently doing the control. The membership functions for the fuzzy sets will be derive from the information available from the domain experts and/or observed control actions. The building of such rules and membership functions require tuning. That is, performance of the controller must be measured and the membership functions and rules adjusted based upon the performance. This process will be time consuming. The basic configuration of Fuzzy logic control based as shown in Fig. 4.1 consists of four main parts i.e. (i) Fuzzification, (ii) knowledge base, (iii) Inference Engine and (iv) Defuzzification.

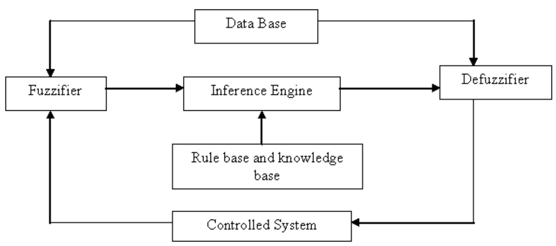


Fig.5 Structure of Fuzzy Logic controller

1 Fuzzification:

Fuzzification maps from the crisp input space to fuzzy sets in certain, input universe of discourse. So for a specific input value x, it is mapped to the degree of membership $\mu_A(x)$. The fuzzification involves the following functions. Measures the value of input variables.

1. Performs a scale mapping that transfers the range of values of input variables into corresponding universe of discourse.

2. Performs the function of fuzzification that converts input data into suitable linguistic variables, which may be viewed as labels of fuzzy sets.

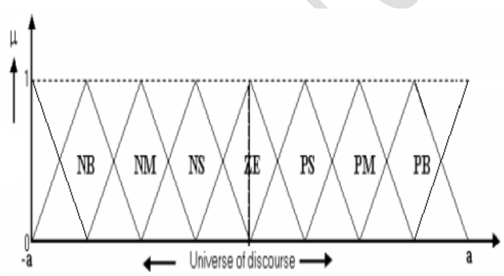


Fig 6 Triangular membership functions

2 Knowledge Base (KB):

Knowledge base comprises of the definitions of fuzzy MFs for the input and output variables and the necessary control rules, which specify the control action by using linguistic terms.

It consists of a database and linguistic control rule base.

1. The database provides necessary definitions, which are used to define linguistic control rules and fuzzy data, manipulation in a FLC.

2. The rule base characterizes the control goals and control policy of the domain experts by means of a set of a set of linguistic control rules.

3 Inference Mechanism:

The Decision – Making Logic Which plays an essential role and contains a set of fuzzy if-then rules such as

IF x is A and y is B then z is C

Where x, y and z are linguistic variables representing two input variables and one control output: A, B and C are linguistic values.

It is kernel of an FLC, it has the capability of simulating human decision making based on fuzzy control actions employing fuzzy implication and the rules of inference in fuzzy logic.

In general, fuzzy systems map input fuzzy sets to output fuzzy sets, fuzzy rules are the relation between input/output fuzzy sets.

4 Defuzzification:

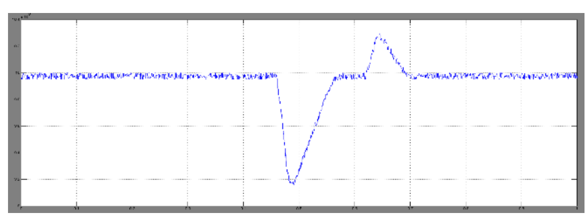
Defuzzification converts the linguistic variables to determine numerical values. Centroid method of defuzzification is used in this study.

(1)A scale mapping, which converts the range of values of input variables into corresponding universe of discourse.

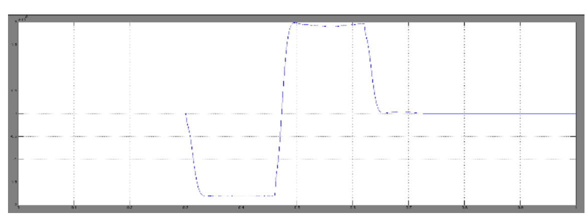
(2)Defuzzification, which yields a non-fuzzy control action from an inferred fuzzy control action.

VI. SIMULATION RESULTS

CASE 1: System responses with reactive power reference step changes.



(A)



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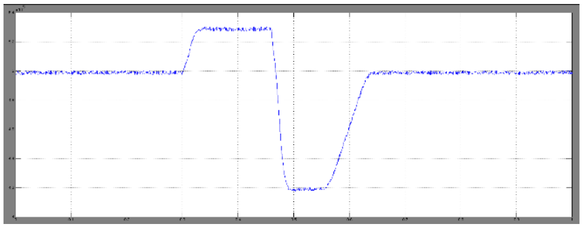
(B)

Fig 7 (A)Active power transfer and (B) Reactive power consumption at inverter



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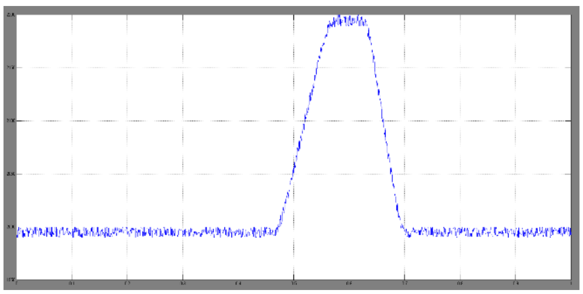
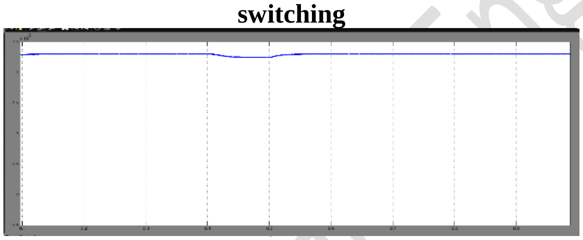


(B)

Fig 8(A)DC voltage and (B) DC current

Case2: System responses with large inductive load switching



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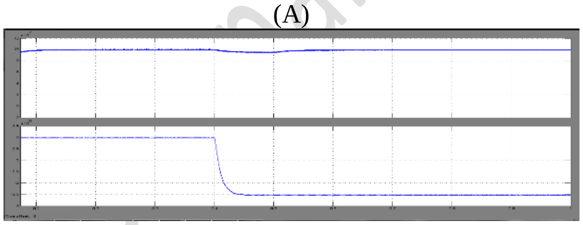

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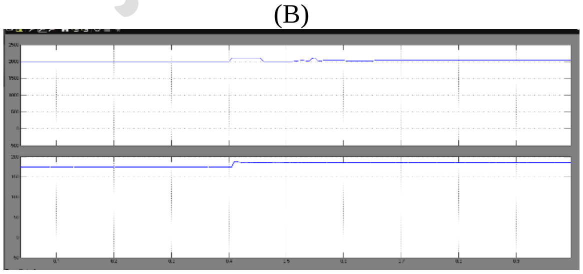

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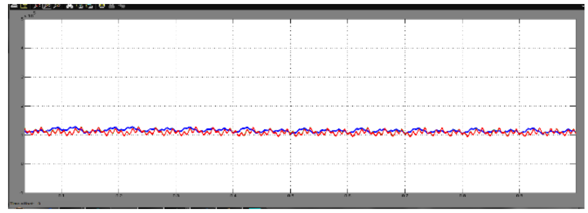

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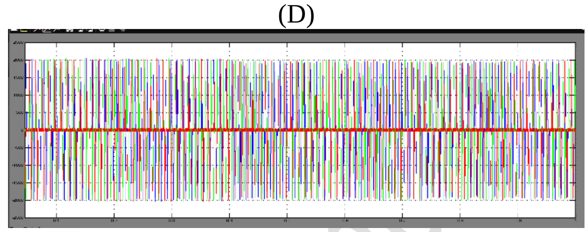

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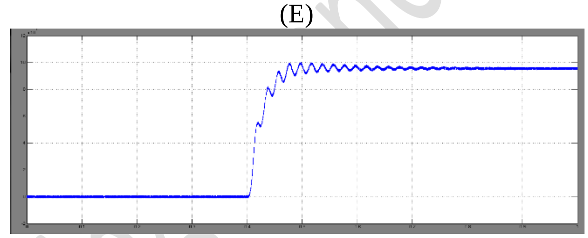
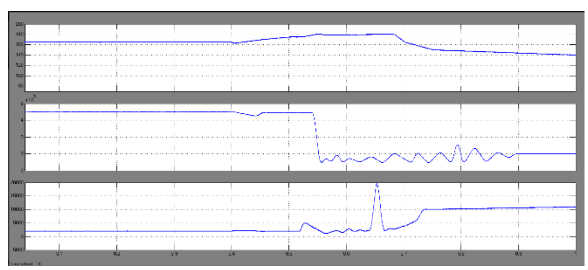


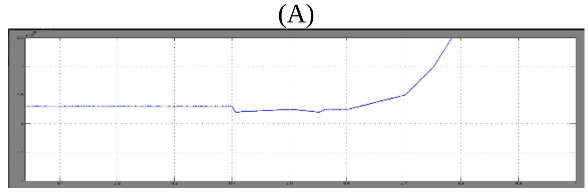
(F)

Fig9. (A)AC voltage (B) Inverter Active and reactive powers (C) DC current and firing angle (D) Capacitor voltages (E) Capacitor currents (F) Induction motor reactive power

CASE 3: System responses of CCC HVDC with large inductive load switching



(A)



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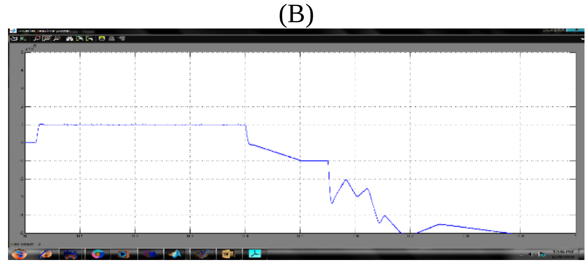
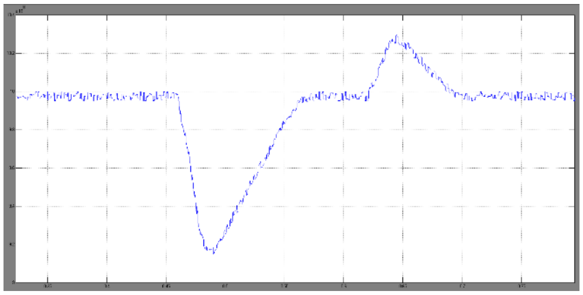


(C)

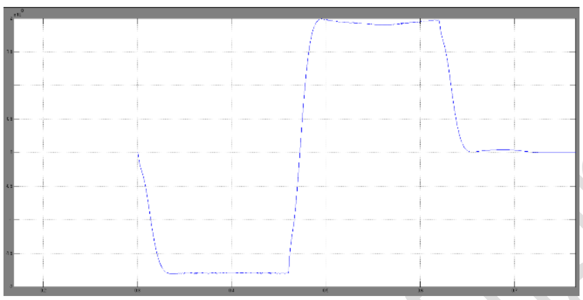
Fig10. (A)Firing angle, DC voltage and DC current
(B) AC voltage (C) Reactive power

EXTENSION RESULTS WITH FUZZY CONTROLLER

Case 1) System responses with reactive power reference step changes

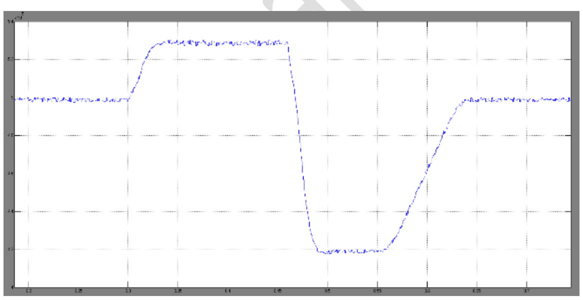


(A)



(B)

Fig 11 (A)Active power transfer and (B) Reactive power consumption at inverter



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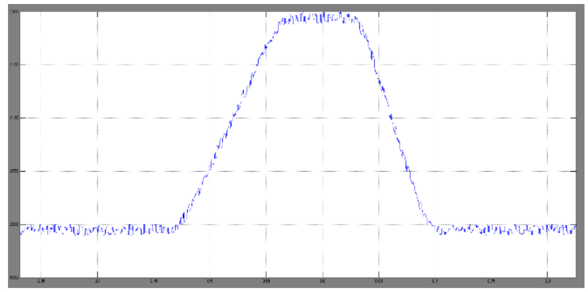
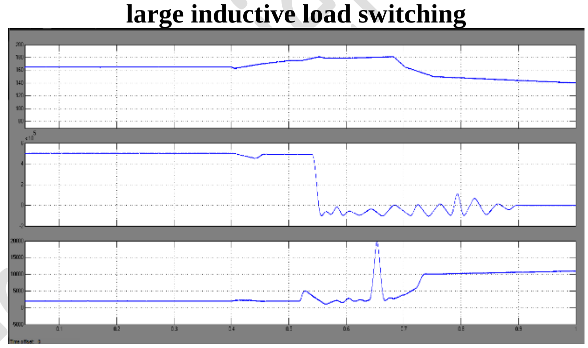


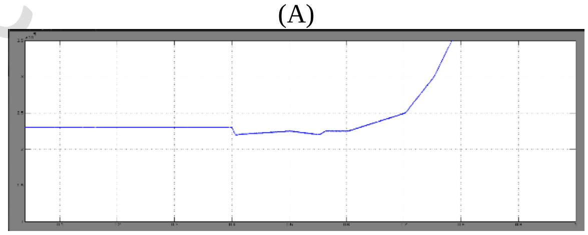
(B)

Fig 12. (A)DC voltage and (B) DC current

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



(A)



(B)

Fig13. (A) 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. The effectiveness of the reactive power/voltage control capability for the proposed system is validated through simulation results using Real Time Digital

Simulator (RTDS). The proposed concept Fuzzy Logic which assists in accurate control of capacitors and makes the system efficient by reducing the consumption of Reactive Power.

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