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Reactive Power and AC Voltage Control of LCC HVDC System with Digitally Tunable Controllable Capacitors

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ABSTRACT

It is well-known that traditional LCC HVDC system is not able to control its reactive power and terminal AC voltages. This paper investigates the reactive power and AC voltage control at the inverter side of the LCC HVDC system with controllable capacitors. The system's ability of operating under negative extinction angle is utilized to achieve a wide range of reactive power control and, in particular, the ability of exporting reactive power. The effectiveness of the reactive power/voltage control capability for the proposed system is validated through simulation results using Real Time Digital Simulator (RTDS). To verify the effectiveness of the reactive power and voltage control, CCC HVDC and LCC HVDC with SVC are also set up in RTDS. The proposed concept makes an integration of Fuzzy Logic which assists in accurate control of capacitors and makes the system efficient by reducing the consumption of Reactive Power. All the results are acquired from the MATLAB simulations and various graphs are plotted.

KEYWORDS: *LCC-HVDC, RTDS, SVC, FUZZY.*

I. INTRODUCTION

Most HVDC schemes in commercial operation today employ line commutated thyristor valve converters.

Line Commutated Converter

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.

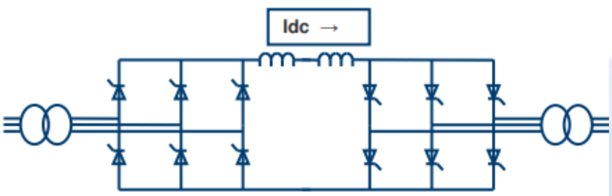


Figure 1. LCC HVDC

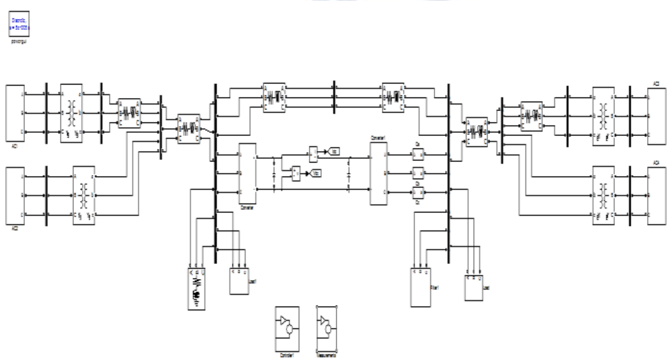


Figure 2. Simulation 1

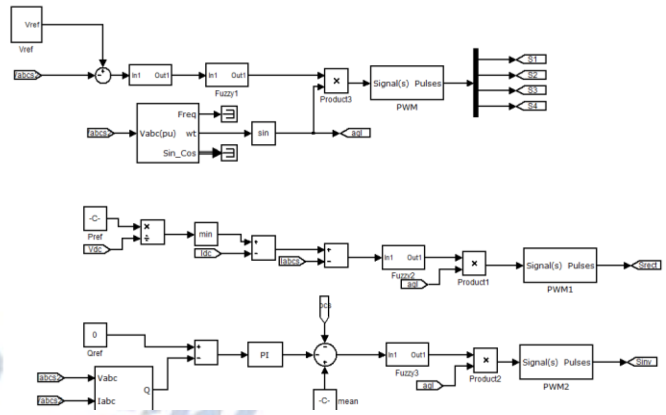


Figure 3.Controller design using conventional method.

II. LCC -HVDC

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.

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 3 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.

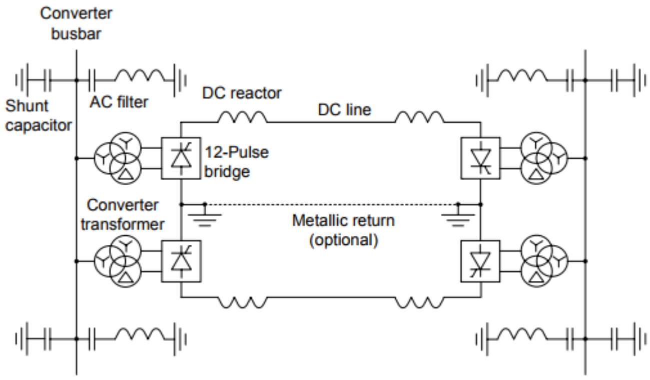


Fig 4: One-line diagram of a two-terminal HVDC system

3.1 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.

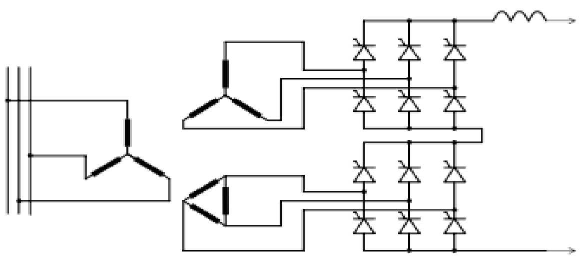


Fig 5: Configuration of a 12-pulse bridge

3.2 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.

3.3 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.

3.4 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.

3.5 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.

3.6 DC Connections

Cables or overhead lines are always present on the pole connections, except in back-to-back systems. On the electrode connections, many existing systems use the ground return in normal operating conditions (monopolar systems) or in emergency conditions (bipolar systems). However, because of environmental opposition, the utilization of ground return is becoming increasingly problematic and the use of metallic return (as indicated in Figure 4), although more expensive, is becoming common, especially for monopolar systems.

IV. Theoretical analysis of reactive power controllability

This section is to examine the reactive power controllability by capacitor insertion and firing angle control. The capacitor insertion strategy and capacitor voltage balancing actions affect the system from three different aspects. Firstly the overlap angle is smaller due to additional commutation voltage from capacitors. Secondly the average voltage across the 6-pulse bridge is increased due to the difference of capacitor voltage change during commutation.

Thirdly the pre-insertion of capacitors for charging purpose also increases the average bridge voltage. In the following, analytical derivations will be presented for all three aspects and then variation of power factor (interchangeably variation of reactive power) as a function of firing angle and extinction angle will be shown. In addition, selection of capacitor voltage level for the desired operating range is also presented.

V. Fuzzy Logic Controller

In HVDC Light transmission systems, active and reactive power is controlled by using different types of controllers. In general, conventional PI controllers are used for this application.

The gain values used in conventional PI controlled system are:

KP = 3; KI = 20 (For P and Q control modes at station 1)

KP = 2; KI = 40 (For DC voltage control mode at station 2)

KP = 3; KI = 25 (For Q control mode at station 2)

But, these controllers are designed to work at a particular operating point; any disturbance may cause deterioration of the controller performance. To avoid such a situation, fuzzy PI controllers are introduced to control above parameters in the HVDC Light transmission systems. It shows the overall structure of the proposed controller. In this research work, four PI controllers are used to get faster response and smaller overshoot. Inner structure of the fuzzy PI controller. The basic fuzzy logic controller is composed of four function blocks.

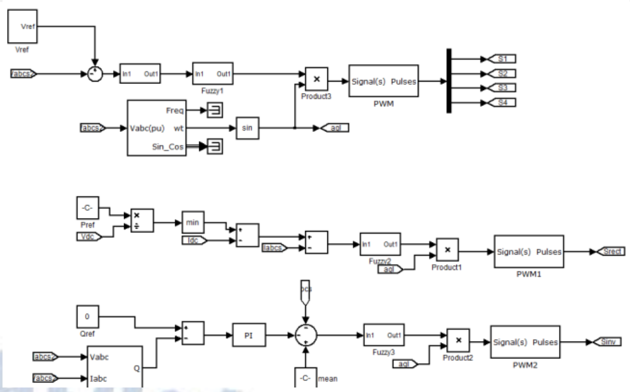


Fig6: Controller design using proposed method

These are fuzzifier block, knowledge base, inference engine and defuzzifier block. There are two inputs for each of the fuzzy logic controller, namely, error (e), change of error (de) and the output known as gain(Kp and Ki) [12]. Here, the data of two inputs i.e. error and change of error are transformed into linguistic variables by fuzzifier. Then, the linguistic variables are processed by the fuzzy rules in the rule base in the form of "If – Then" through fuzzy implication.

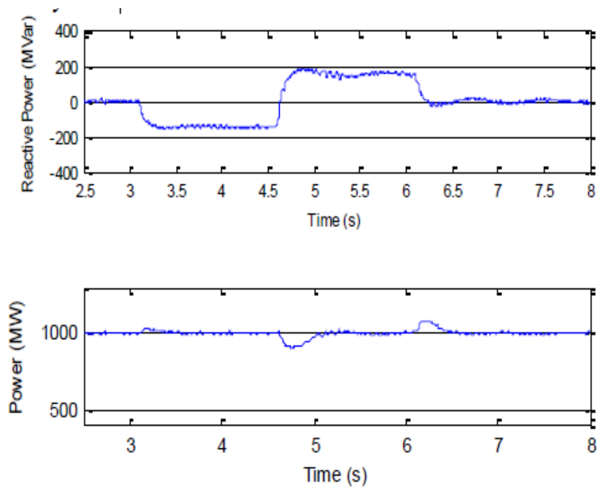
To fuzzify both input data and output, triangular membership function set is used in this paper with five linguistic variables viz, Negative large (NL), Negative small(NS), zero (Z), positive small (PS) and positive large (PL). The membership functions used for the input and output variables in the fuzzy logic tool box are shown in Fig.6. The knowledge base unit has two components, the data base and the rule base.

VI. EXPERIMENTAL RESULTS

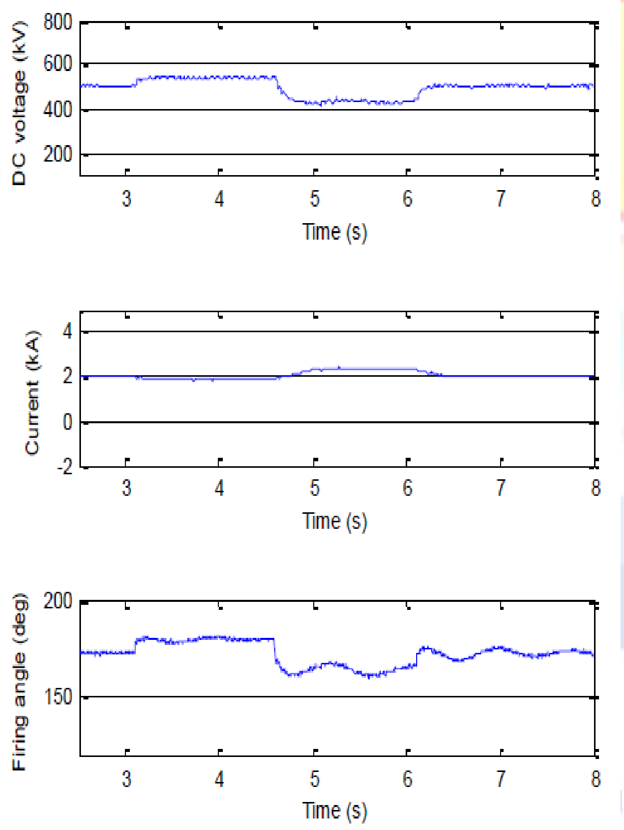
This section presents the simulation results of reactive power control and inverter AC voltage control of the LCC HVDC system with controllable capacitors. The nominal operating point for both cases is designed so that the inverter side is absorbing zero reactive power and sending rated active power at rated DC and AC voltages. The capacitor banks are removed and transformer turns ratio is modified to meet the rated working condition. The values of capacitors are 585uf and its voltage level is chosen to be 110 kV. The rectifier side is controlling the active power transfer by controlling the DC current. The AC systems at both sides are kept the same as the CIGRE HVDC benchmark model. The whole system is modelled in RTDS with a small simulation time-step of3.6us .

A. Reactive Power Control

Fig. 7 shows the system responses following changes of reactive power reference. In this simulation, the reactive power reference is initially set to zero and changes to -150 MVar at 3.1s, then increases to 150 MVar at 4.6s and finally changes back to zero at 6.1s. Negative reactive power indicates that the inverter is exporting reactive power to the AC system.



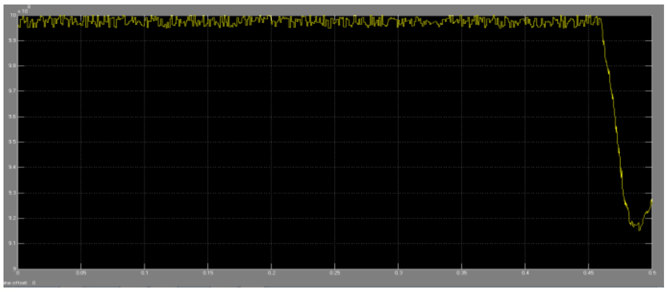
(a), (b)



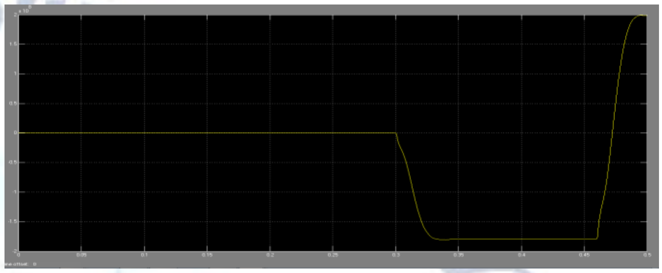
(c), (d), (d)

Fig. 7. System responses with reactive power reference step changes. (a) Reactive power consumption at inverter; (b) Active power transfer; (c) DC voltage; (d) DC current; (e) Inverter firing angle.

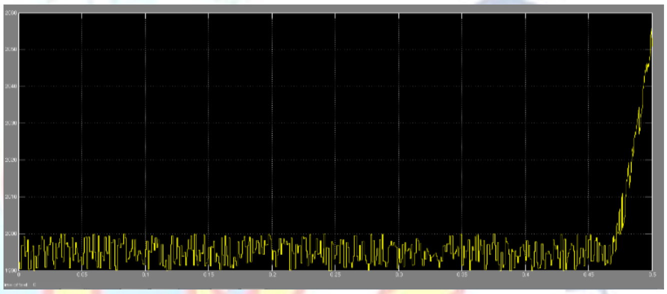
Simulation response.



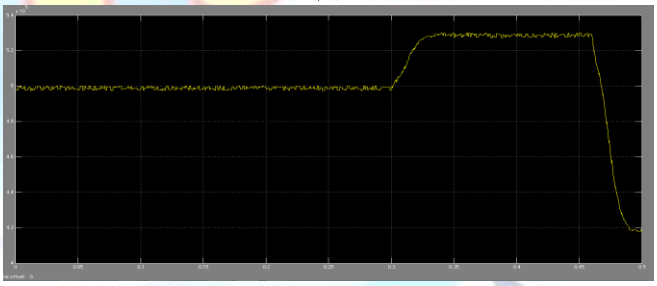
(a)



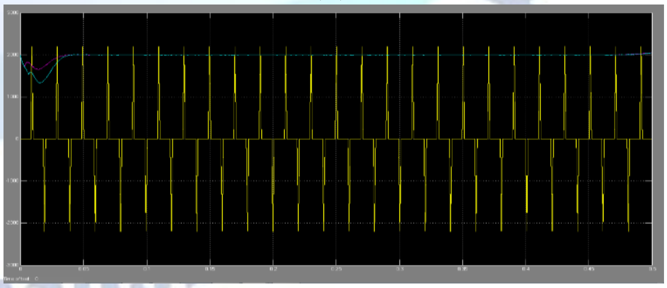
(b)



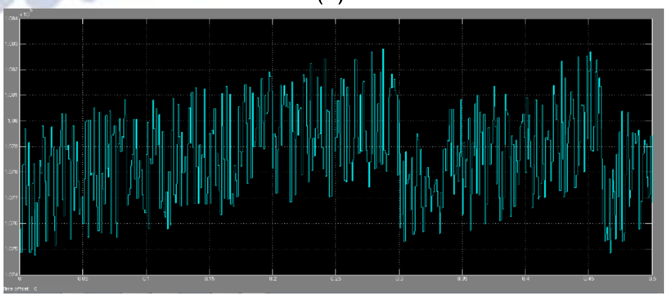
(c)



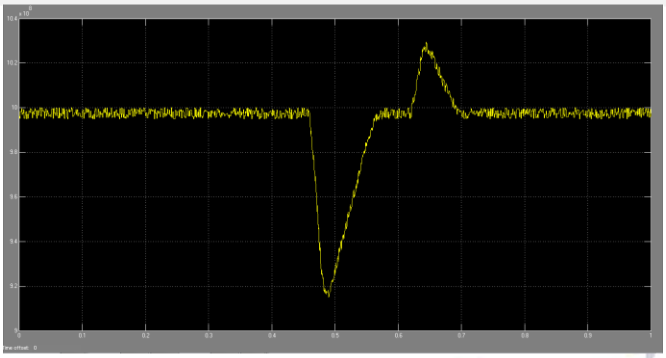
(d)



(e)



(f)



(g)

Fig (a), (b), (c), (d), (e), (f), (g) output values before Fuzzy and after fuzzy logic in the entire system

VII. 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 makes an integration of Fuzzy Logic which assists in accurate control of capacitors and makes the system efficient by reducing the consumption of Reactive Power .

Coming to the proposed theory of substrate coupled inductorsHere the error regarding load current and the reference value will be driven to PI controller which guides them in to the pulse generator. As the result distortions and harmonics will be mitigated

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