A Study on CCC(Capacitor Commutated Converter) and CSCC(Controlled Series Capacitor Converter) for HVDC System

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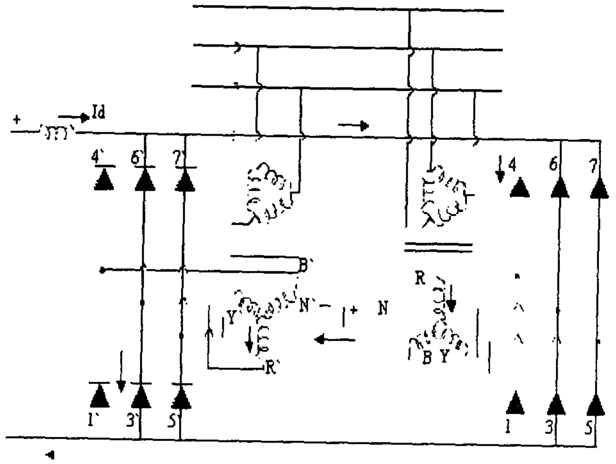
Abstract - This paper deals with two non-conventional HVDC system, that are, the Capacitor Commutated Converter (CCC) in which series capacitors are included between the converter transformer and the valves, and the Controller Series Capacitor Converter (CSCC), based on more conventional topology, in which series capacitors are inserted between the AC filter bus and the AC network. The simulation waveforms show that if these compare to conventional HVDC, these HVDC systems have many advantages in steady-state and transient performance.

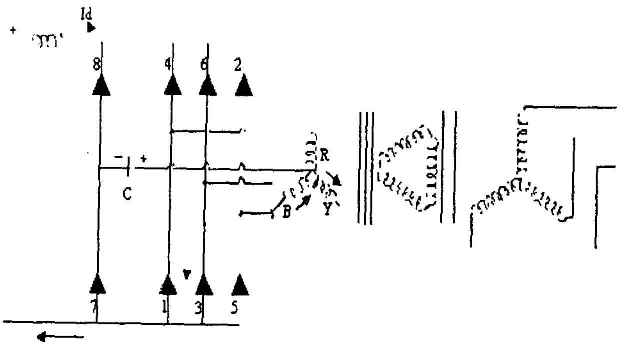
Keywords : HVDC, CCC(Capacitor Commutated Converter), CSCC(Controlled Series Capacitor Converter), PSCAD/EMTDC.

I. INTRODUCTION

CCC(Capacitor Commutated Converter) with series capacitors in the transformer windings was considered in the early 50s[1]. Fig. 1 shows the artificial forced commutation converter in early 50s.



(a) Forced commutation converter (1) proposed in the early 50s.



(b) Forced commutation converter (2) in the early 50s.

Fig. 1 Cheju-Haenam HVDC system control diagram

However, there was a drawback because there was no economic way to mitigate the inherent severe transient over-voltages. The interest resumed in 80s., mostly due to the development of metal oxide varistors(ZnO). More recently, the new series capacitor commutated converter has been suggested as an advanced HVDC technology, so called CSCC(Controlled Series Capacitor Converter), due to the development of power electronics and power system technology. The advantage of this types are following as :

In steady-state, the most important advantage of this types are the very low and almost flat reactive power requirement of a CCC and CSCC, which eliminates the need for large shunt compensation and the need to switch it in steps.

In transient state, also, the advantages of this type become even larger: one is that the low shunt compensation means low over-voltages upon load rejection; another is the self-regulating characteristic of a capacitor behind a thyristor about to commutate: as long as the current continues, the counter voltage keeps on growing, helping in bringing about commutation even if the AC system is weak.

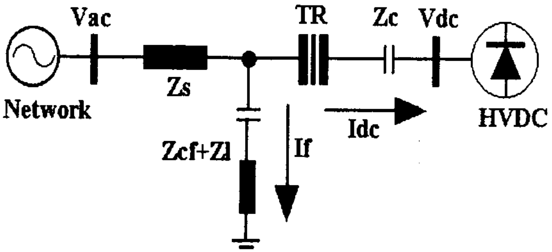
This paper deals with the characteristics of CSCC and CCC, The studies are conducted using analytical formulations a well as by simulation using the PSCAD/EMTDC electromagnetic transients simulation program and additionally program.

II. COMPARISON OF CCC AND CSCC

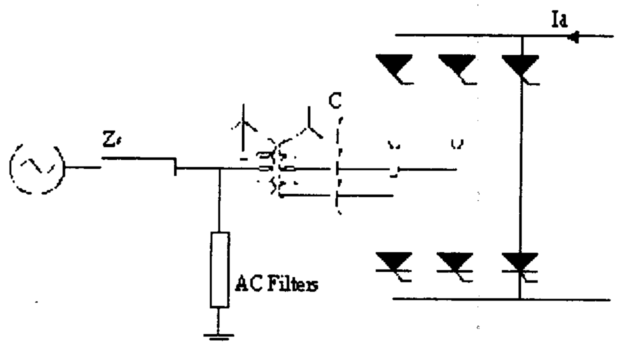
A. CCC Configuration

Fig. 1 shows a basic 6-pulse CCC. In Fig.2 (a), the role of CCC capacitor, Z_c, is explained as Eq.(1), following as ;

$$V_{dc} = V_{ac} - Z_x x(I_f + I_{dc}) - Z_c I_{dc} \quad \text{...........} \ (1)$$



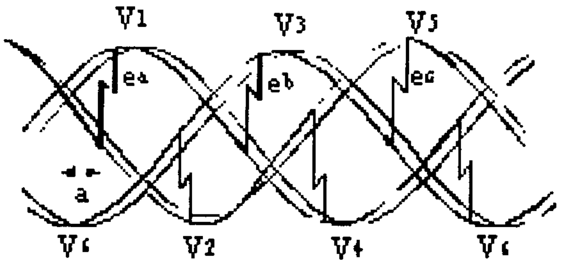
(a) CCC equivalent circuit



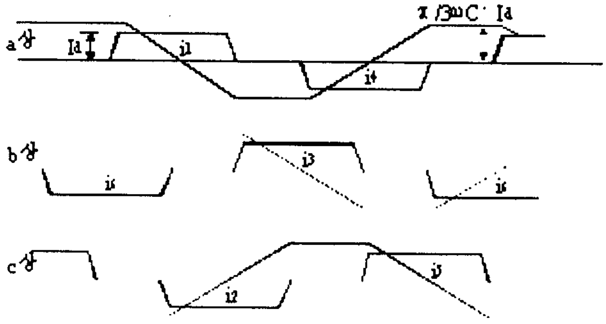
(b) Six-pulse type CCC

Fig. 2. Capacitor commutated converter(CCC)

The DC current flows through each phase capacitor in either forward or reverse direction during the conduction of the corresponding upper or lower group thyristor in that phase. The capacitors are charged with a polarity that aids in the commutation process. Fig. 3 shows the waveform of the each part in CCC.



(a) Voltage waveform of CCC



(b) Current waveform of CCC

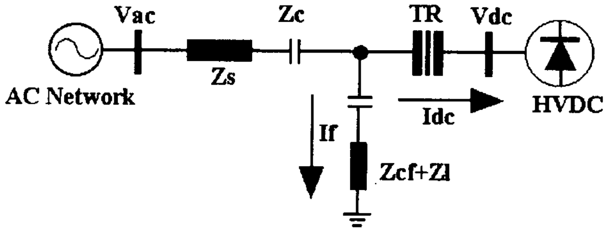
Fig. 3. Voltage and current waveform of CCC

As Fig. 3, the firing angle α of CCC can be increased to a value well beyond 180°, which would be impossible with a conventional converter. Consequently, CCC can be used in a weak inverter HVDC system because of the extension of extinction angle.

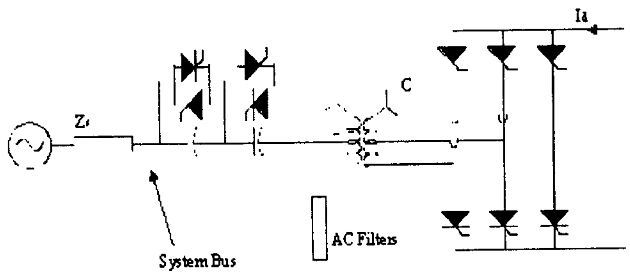
B. CSCC Configuration

Fig. 4 shows CSCC which the series capacitors are inserted at the connection of the filter bus to the AC system. In this type, the capacitor value can be adjusted in the manner similar to that used in thyristor controlled series compensation(TCSC) schemes. Comparing to CCC, the advantage of this type is that the possibility of ferroresonance can be avoided. Eq. (2) explain the characteristics of CSCC type.

$$V_{dc} = V_{ac} - (Z_s + Z_c) x(I_f + I_{dc}) \quad \text{...........} \ (2)$$



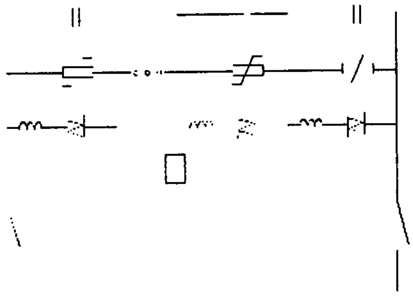
(a) CSCC Equivalent Circuit



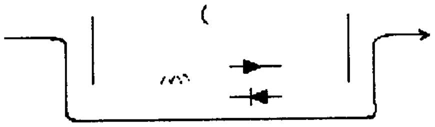
(b) Six-Pulse type CSCC

Fig. 4. Controlled series capacitor converter

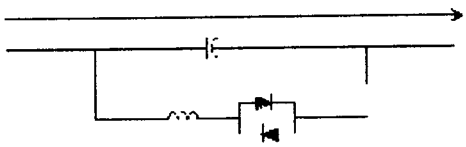
The thyristor controlled series capacitor(TCSC) has 10 series stages and hence the capacitance value can be varied by bypassing (either fully or partially) the series stages. This bypass action is automatically triggered by the AC network fault and the capacitor value is ramped back to its full value zero recover.



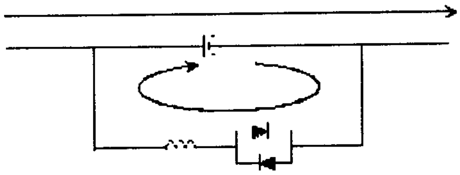
(a) TCSC Schem.



(b) Bypassed



(c) Inserted with no thyristor valve current

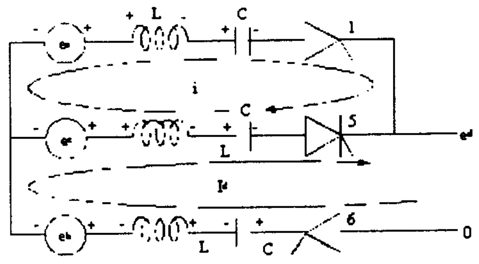


(d) Current circulation through thyristor valve

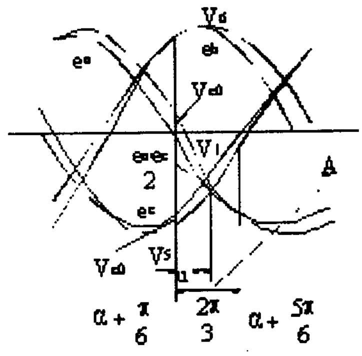
Fig. 5. TCSC action

C. Theoretical Background of CCC

The advantages of CCC can be represented in Eq. (1), from this equation, the role of capacitor "C" is, as shown from (3) to Eq. (5), to increase the commutation margin in commutation periods. This means that CCC has a robust characteristics against cummutation failure in weak AC system.



(a) Commutation Period



(b) Voltage Waveforms of CCC

Fig. 6 Commutation phenomena and Voltage waveform of CCC.

$$V_5 = e_c - L\frac{d(I_d - i)}{dt} - \frac{1}{C}\int (I_d - i)dt \text{ .... } (3)$$

$$V_1 = e_a - L\frac{di}{dt} - \frac{1}{C}\int idt \text{ .... } (4)$$

$$V_6 = e_b - L\frac{dI_d}{dt} + \frac{1}{C}\int i_d dt \text{ .... } (5)$$

$$(dI_d / dt = 0)$$

From Fig. 6, Eq. (7) is the relation between currents during commutation period, Eq. (8) shows the relation of the extinction angle. And the DC voltage equation of CCC is Eq. (10) and Eq. (11). In Fig. 6 (b), A is a actual extinction angle.

$$2L\frac{di}{dt} + \frac{2}{C}\int idt = (e_a - e_c) \text{ .... } (6)$$

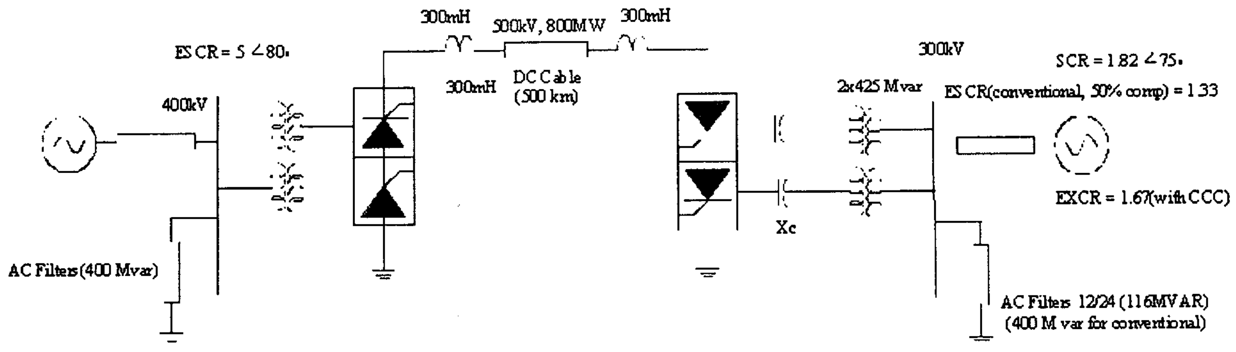


Fig. 7. Simplified single-line diagram of DC system (show with CCC option)

$$i=-\frac{\sqrt{2}}{\sqrt{3}}E(\cos(\omega t)-\cos(\omega t+\frac{2\pi}{3}))\frac{1}{2\omega L}-\frac{\pi}{3\omega C}\frac{I_d}{L}t+i_o \quad (7)$$

$$\cos\alpha-\cos(\alpha+\mu)=\sqrt{2}(\omega L-\frac{\pi}{3\omega C}\mu)\frac{I_d}{E} \ldots\ldots\ldots\ldots(8)$$

$$\cos\alpha=-\cos\gamma+\sqrt{2}(\omega L-\frac{\pi}{3\omega C}\mu)\frac{I_d}{E} \quad \ldots\ldots\ldots\ldots\ldots$$

(9)

$$E_d=-\frac{3\sqrt{2}}{\pi}E\cos\alpha-\frac{3}{\pi}(\omega L-\frac{\pi}{3\omega C}\mu)I_d \quad \ldots\ldots\ldots$$

(10)

$$E_d=-\frac{3\sqrt{2}}{\pi}E\cos\gamma+\frac{3}{\pi}(\omega L-\frac{\pi}{3\omega C}\mu)I_d \quad \ldots\ldots\ldots$$

(11)

Power factor :

$$\frac{\cos(\alpha+\mu)+\cos\alpha}{2}=\cos\alpha-(\omega L-\frac{\pi}{3\omega C}\mu)\frac{I_d}{\sqrt{2}E}$$

$$=-\cos\gamma+(\omega L-\frac{\pi}{3\omega C}\mu)\frac{I_d}{\sqrt{2}E} \quad \ldots(12)$$

III. STEADY STATE PERFORMANCE

In order to analyze the characteristics of CCC HVDC, the HVDC shown in Fig. 7 is made, this HVDC is connected to a 300kV AC bus. The DC systems in either case are rated at 500kV, 1.6kA.

One major advantage of these topology is that the serise capacitors assist in the commutation process. Thus the apparent extinction angle viewed from the 300kV AC bus bar can approach very small, and even negative valu4es depending on the size of the selected series capacitor. The apparent extinction angle γ_{app} is the electrical angle corresponding to the time at which the valve turns off to the positive zero crossing of the corresponding apparent commutation(line-line) voltage on the AC bus bar. The actual γ is of course larger because the real commutation voltage is the sum of the line-line AC bus bar voltage and the series capacitor voltages. The small value of γ_{app} results in an improved power factor and diminishes the requirement for shunt reactive power compensation.

Because the voltage on the series capacitor actually increases with DC current, the natural tendency for the extinction angle on an increase in DC current is to increase. This is the converse of the situation for the conventional converter in which an increase in DC current decreases γ, thereby bringing the converter closer to the commutation failure limit. This characteristic of the CCC or CSCC options is very favourable particularly for long cables. In these cases, a sudden lowering of inverter AC voltage, say due to a remote AC fault, results in an sudden increase in DC current. The current controller on the rectifier has negligible effect on this over current which is primarily due to a discharge of the cable capacitance. The probability of communication failure is reduced due to the natural tendency for γ to increase with increasing DC current.

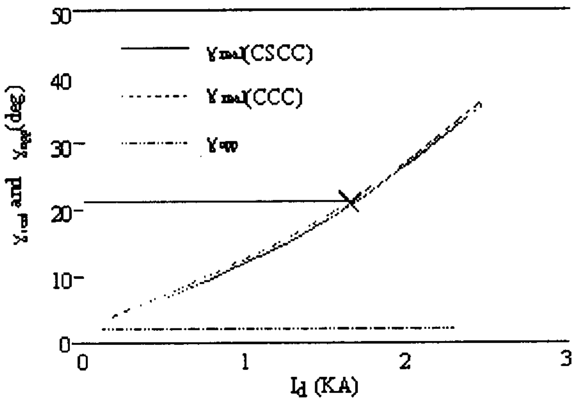


Fig. 8. Actual and apparent extinction angles, CCC

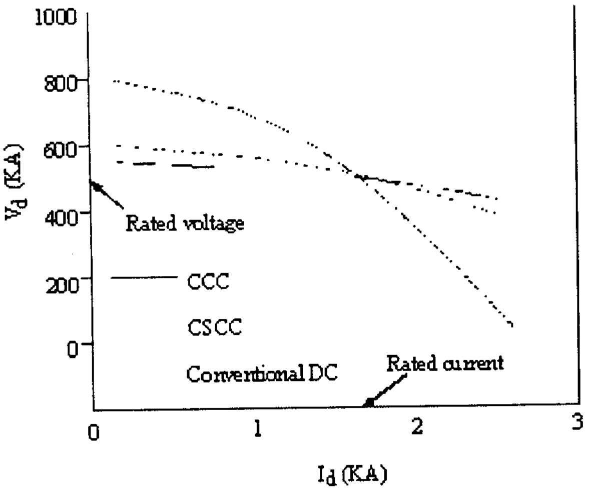


Fig. 9. DC Voltage v/s I_d for CEA Control Mode

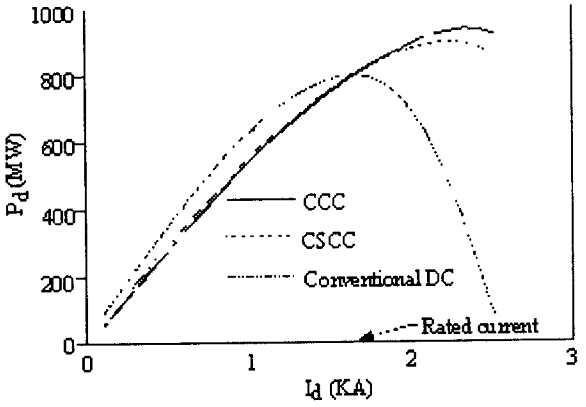


Fig. 10. Max. Available Power v/s I_d for CEA control Mode

Fig. 8 shows the real extinction angle as a function of DC current calculated from theory. Also, a theoretically calculated plot of DC voltage versus current is shown for the two options in Fig. 9. As can be seen, the DC voltage for both the CCC and CSCC options has a much smaller slope as compared with the conventional case. This gives a much larger value for maximum available power(MAP) as compared to that for a conventional HVDC converter as (operated at a typical γ = 18°) seen from the theoretically calculated curves in Fig. 10. In Fig. 10, if the HVDC system is operated in the power-control mode, points on the power curve beyond the MAP point are unstable. In fact, for the given system short circuit ratio, the rated operating point would be past the stability limit of 0.94 p.u for the conventional option. This stability limit is increased to 1.44 p.u and 1.34 p.u respectively with the CCC and CSCC options.

IV . TRANSIENT PERFORMANCE

Fig. 11 shows characteristic waveforms of CCC HVDC at three phase fault. The fault is applied at 1.5s into the run and has a 5 cycle duration.

In this simulation, the control method in rectifier is current control and the control method in inverter is γ control. Therefore, as shown in Fig. 10, DC current is not changed, DC voltage is decreased to zero. At this time, Active power is decreased according to DC voltage decrease, otherwise, reactive power is increase for fault duration. However, since an actually system has several controller and control actions, this actions can not be appeared. And for fault, current can be changed slightly.

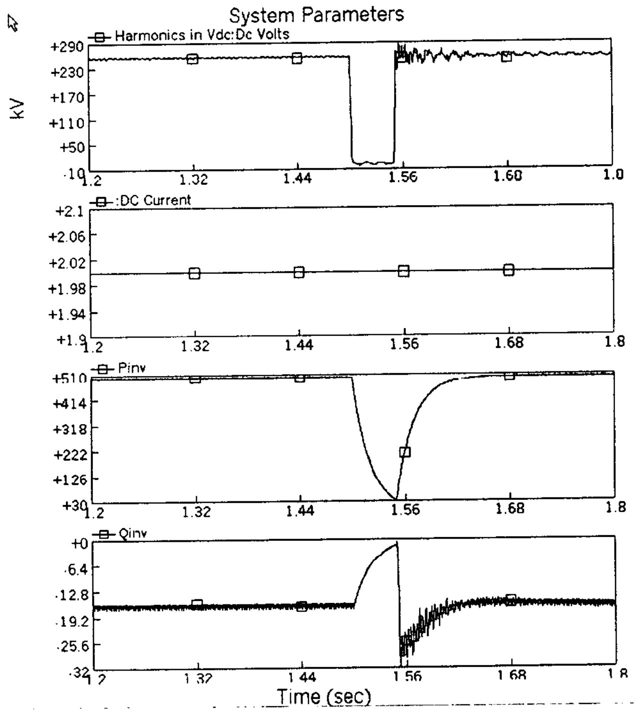


Fig. 11. Characteristic waveforms of CCC HVDC at three phase fault. (a: DC voltage, b: DC current, c: Active power and d: Reactive power)

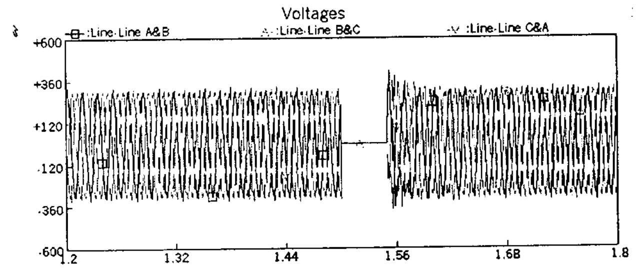


Fig. 12. Current waveforms of CCC HVDC at three phase fault.

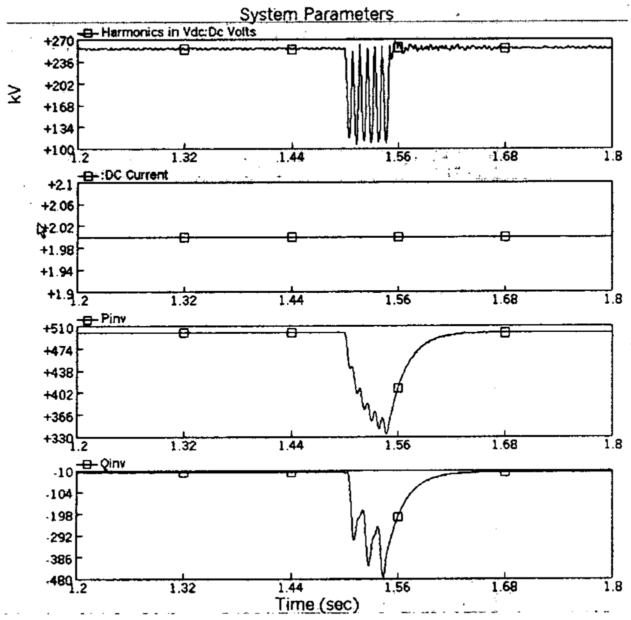


Fig. 13. Characteristics waveforms of CCC HVDC at single phase fault. (a: DC voltage, b: DC current, c: Active power and d: Reactive power)

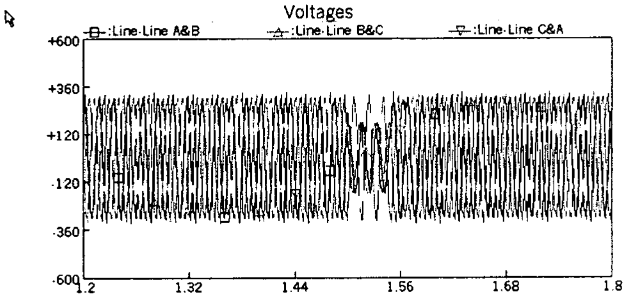


Fig. 14. Current waveforms of CCC HVDC at single phase fault.

The waveforms in Fig. 11 show that the fault recovery of CCC HVDC has a good performance because of the capacitor action even if no consider a delicate control algorithm.

Also, Fig. 13 show characteristic waveforms of CCC HVDC at single phase fault. Compare to a three phase fault case, in this case, there is a different feature, that is, power is increase for the fault duration.

V. CONCLUSIONS

Finally, according to above representation. The advantages of CSCC and CCC are following as :

(1) Low absorption reactive power(compared to a conventional HVDC, 25%)
(2) Maximum power is increased(compared to a conventional HVDC, 125%)
(3) Ferroresonance can be avoided(CSCC).
(4) Robust HVDC system in weak system, because a extinction angle is the function of DC current.
(5) The unbalance of firing pulses does not cause the commutation failure due to feedback between HVDC and AC system.

VI. REFERENCES

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