STUDY OF VOLTAGE AND HARMONIC STABILITY OF CAPACITOR COMMUTATED CONVERTERS APPLIED TO HVDC/BTB

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ABSTRACT - Voltage and harmonic stability characteristics of capacitor commutated converters applied to a BTB (back to back) system (CCC-BTB) are analyzed and compared to characteristics of a BTB system composed of conventional line commutated converters (LCC-BTB). About 1.6 times larger safe operating regions can be obtained for the CCC-BTB system compared to the latter. The CCC-BTB system results in no harmonic instability problem as it has no shunt reactive compensators in the station and the adjoining AC system generates no low anti-resonance points.

1. INTRODUCTION

Application of capacitor commutated converters (CCCs) for HVDC/BTB (back-to-back) systems has been a topic of study worldwide [1]-[2]. The HVDC/BTB system composed of CCCs has a lower system cost compared with the HVDC/BTB system composed of conventional line commutated converters (LCCs) and it can operate safely even in a weak AC system. Before applying the CCCs to the HVDC/BTB system, however, static and dynamic characteristics such as behaviors during AC/DC system faults, AC voltage stability and harmonic instability under various AC conditions must be known.

In this paper, voltage and harmonic stability characteristics of CCCs applied to a BTB system (CCC-BTB) are analyzed and compared to a BTB system composed of conventional LCCs (LCC-BTB).

2. ANALYSIS OF VOLTAGE STABILITY

The voltage stability can be used to determine the AC voltage stability of the AC/DC connecting bus by a power flow calculation program. In the program, the inverter of the BTB system is presented as a P-Q designated generator model, while the rectifier is a P-Q designated load model. Their active power P and reactive power Q are calculated by P-Q equations explicitly using the operating point of CCC-BTB and LCC-BTB which is calculated by the power flow calculation program. The calculation flow is shown in figure 1. The AC/DC connecting bus voltages Vac are calculated through a convergence process using the P-Q equations and the power flow calculation program. First, assuming Vac, the DC currents are designated and the control angel α, P and Q of the converter are calculated using the P-Q equations. Then, Vac is calculated using P and Q from the power flow calculation program. If the calculated Vac is different from the assumed Vac, then, the calculated Vac is used to recalculate α, P and Q. Then P and Q are used to calculate Vac again. These calculation processes are repeated until the voltages converge. The taps of converter transformers need to be considered.

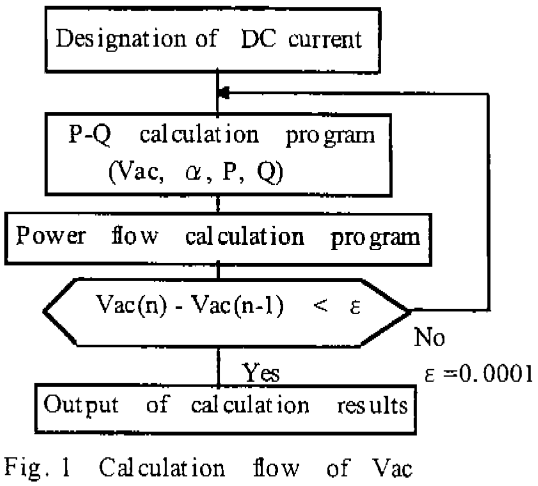

Fig. 1 Calculation flow of Vac

Calculation Conditions

The impedance map of the AC/DC system studied is shown in figure 2. The short circuit ratio (SCR) of converter 2 is varied by changing line impedance of the

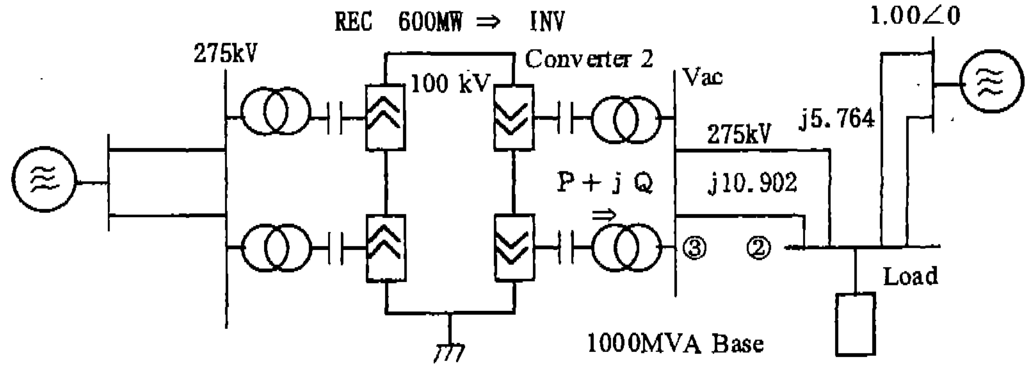

Figure 2 Impedance map of AC/DC (CCC-BTB) system

Table 1 Calculation conditions

Items		Constants
Rated DC voltage (kV)		50
Rated DC current Id (kA)		6
Trans-former	capacity (MVA)	340
	secondary voltage (kV)	39.7 (0.96 pu)
	%Z (pu)	0.12
	taps	0.87-1.13
Commutated capacitor (F)		0.001771 (0.4 pu)
Capacitor voltage (kV)		11.65 (Id=1.0 pu)
Margin angle (deg.)		20
Loss	Converter (Ω)	0.092
	DC reactor (Ω)	0.017
Frequency (Hz)		50

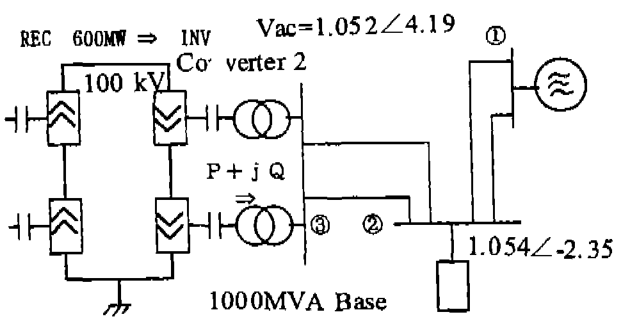

Fig. 3 Calculation results of power flow

AC system. AC filters and var compensators of both CCC-BTB and LCC-BTB are neglected in the voltage stability study. For both calculations conditions are the same. The AC/DC system conditions are shown in Table 1. The power flows and AC voltages in the BTB system being stop are shown in figure 3. The initial bus voltage of the AC/DC connecting point Vac is 1.052 pu.

Calculation Results

Figure 4 shows the calculation results of Vac and P on the inverterside ofthe CCC-BTB and LCC-BTB systems versus the DC current when the SCR is 5. Maximum available power (MAP) is 1.82 pu for the CCC-BTB, while it is 1.14 pu for the LCC-BTB. Vacs are 0.80 pu and 0.72 pu, respectively. The drop of Vac for the LCC-BTB is larger than that of the CCC-BTB.

Figure 5 shows the calculation results of Vac and MAP on the inverterside of the CCC-BTB and LCC-BTB systems versus SCR. The MAP of the CCC-BTB is 1.6 times larger than that of the LCC-BTB, for all SCRs.

Figure 6 shows the calculation results of Vac and P on

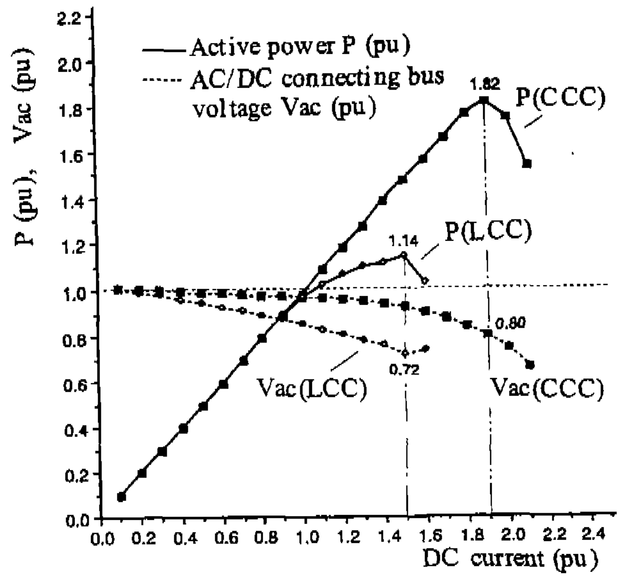

Fig. 4 Calculation results of Vac and P vs. DC current (inverter operation)

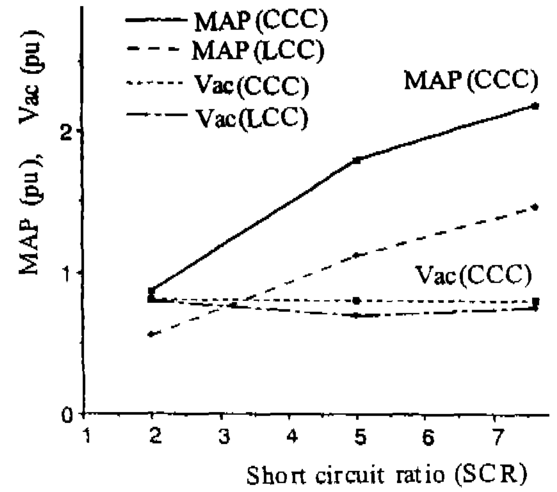

Fig. 5 Calculation results of Vac and MAP vs. SCR (inverter operation)

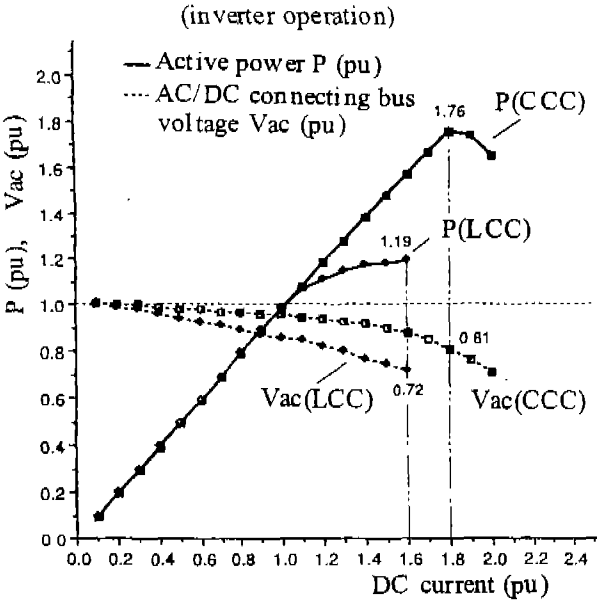

Fig. 6 Calculation results of Vac and P vs. DC current (rectifier operation)

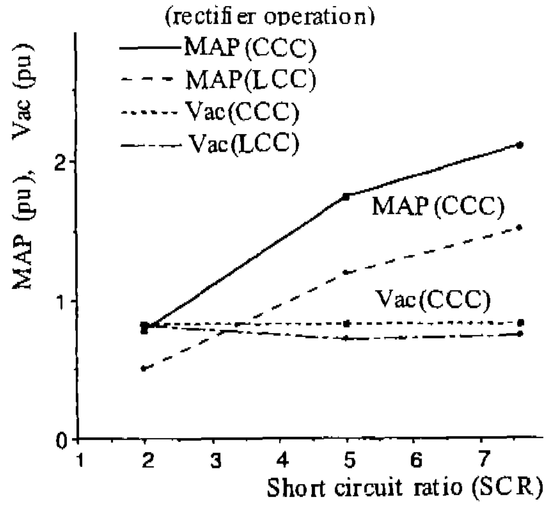

Fig. 7 Calculation results of Vac and MAP vs. SCR (rectifier operation)

the rectifierside of the CCC-BTB and LCC-BTB systems versus the DC current when the SCR is 5. The MAP is 1.76pu for the CCC-BTB, while it is 1.19pu for the LCC-BTB. Vacs are 0.81 pu and 0.72 pu, respectively. The drop of Vac for the LCC-BTB is larger than that of the CCC-BTB.

Figure 7 shows the calculation results of Vac and MAP on the rectifierside of the CCC-BTB and LCC-BTB systems versus SCR. The MAP of the CCC-BTB is 1.6 times larger than that of the LCC-BTB for all SCRs. The results have the same tendencies for both inverter and rectifier operations.

3. ANALYSIS OF HARMONIC STABILITY

The harmonic instability of the CCC-BTB is studied by eigen values of the harmonic transition matrix obtained from multiplication of the AC system harmonic impedance matrix and the DC system harmonic admittance matrix [3].

Definition of Harmonic Transition Matrix

When harmonic AC currents are assumed to be generated from the converters due to some disturbances in the AC systems, the small change in AC currents at the commutation number of times m and m-1 after the disturbances is defined as Δ Iac(m) and Δ Iac(m-1), respectively, where Δ Iac is an n-th order small change of the harmonic AC current vector. Relationships between Δ Iac(m) and Δ Iac(m-1) can be presented in the following equations.

$$\Delta Iac(m)=[Ydc]\Delta Vac(m-1) \quad (1)$$

$$\Delta Vac(m-1)=[Zac]\Delta Iac(m-1) \quad (2)$$

Substituting eq. (2) into eq. (1) leads to eq. (3).

$$\Delta Iac(m)=[Ydc][Zac]\Delta Iac(m-1) \quad (3)$$

Where [Ydc] indicates the n-th order harmonic admittance matrix of the DC system and [Zac] indicates the n-th order harmonic impedance matrix of the AC system. Then, the harmonic transition matrix [S] is defined by the following equation.

$$[S]=[Ydc][Zac] \quad (4)$$

Eq. (3) is rewritten to eq. (5).

$$\Delta Iac(m)=[S]\Delta Iac(m-1) \quad (5)$$

When eigen values and eigen vectors of the harmonic transition matrix [S] are indicated by $\lambda 1$, $\lambda 2$, $\lambda 3$,…, λn and X 1, X 2, X 3, …, X n respectively, eq. (5)

can be rewritten as eq. (6).

$$\Delta Iac(m)=[S]^{m}\ \Delta Iac(0) = C1\cdot\lambda_1\cdot X_1 + C2\cdot\lambda_2\cdot X_2 + C3\cdot\lambda_3\cdot X_3 + \cdots + Cn\cdot\lambda_n\cdot X_n \quad (6)$$

Where Δ Iac(0) shows the n-th order small harmonic AC currents immediately after the disturbances and C1, C2 $\cdots$Cn are constants determined by the initial condition of Δ Iac(0).

From eq. (6), it is known that when the magnitude of all eigen values λ_i ($i=1, 2, \cdots n$) is smaller than 1.0, the AC/DC system is stable because Δ Iac(m) decreases as m grows larger. Otherwise, the AC/DC system becomes unstable because Δ Iac(m) increases with m.

The AC/DC system of harmonic instability can be judged by examining the eigen values of the harmonic transition matrix [S].

Calculation Conditions

The same calculation conditions, except AC filters and var compensators, are used to study the harmonic instability. The constants of AC filters and var compensators are shown in table 2.

Table 2 AC filter and var compensator

	Item		R(Ω)	L(H)	C(μF)	(MVA)
CCC	Commu. cap.				0.0017	
	Transformer			0.085		340.0
	AC filter	11th	5.777	0.1673	0.501	12.0
		13th	7.315	0.1792	0.335	8.0
		HP	163.3	0.00722	2.438	58.0
LCC	Transformer			0.1275		
	AC filter	11th	1.238	0.07168	1.169	14.0
		13th	6.502	0.0796	0.754	10.0
		HP	278.5	0.01232	1.429	28.0
	Var compensator			0.05015	12.12	288.0

Calculation Results

Figures 8 and 9 show results of the 3rd harmonic impedance of the AC system and the maximum eigen value, which is due to the 3rd harmonic AC impedance and AC currents, versus SCR, respectively. The DC current is 1.0 pu and control angle is set 20 degrees for both the CCC-BTB and LCC-BTB systems. No anti-resonance frequency points can be seen for either the

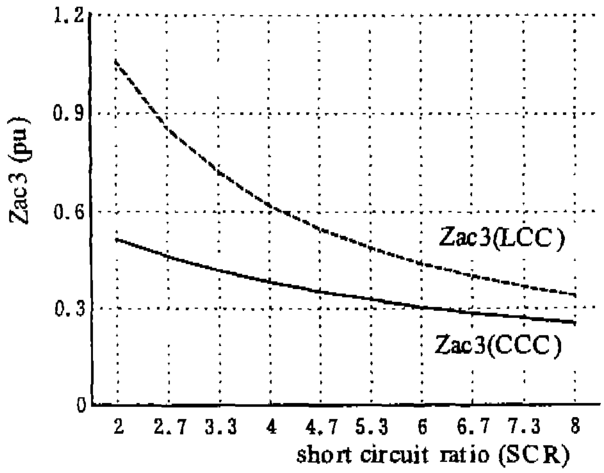

Fig. 8 Calculation results of 3rd harmonic impedance Zac3

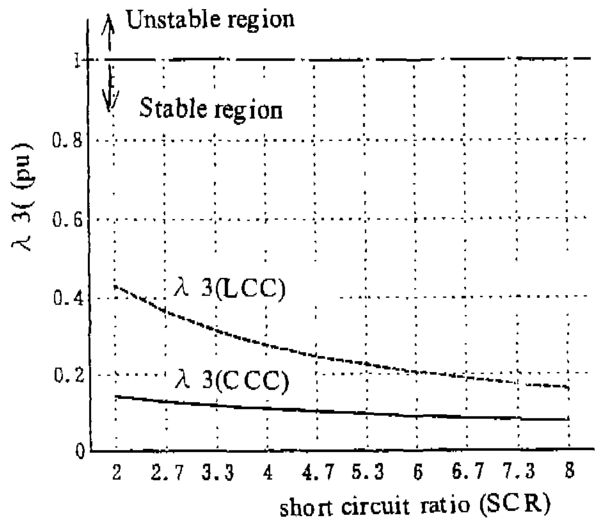

Fig. 9 Calculation results of eigen value of 3rd harmonic

CCC-BTB or LCC-BTB and the eigen values are less than 1.0 for both. BTBs, Both CCC-BTB and LCC-BTB systems are stable at the 3rd harmonic. The eigen values and impedance of the BTB-LCC are a little bit larger than those of the BTB-CCC.

When the DC currents are changed, the results are the same as for the DC current of 1.0 pu and both systems result in stable harmonic conditions.

4. CONCLUSION

Voltage and harmonic stability of CCCs applied to a BTB system were analyzed and compared to the BTB system composed of conventional LCCs. The maximum available power of the CCC-BTB was about 1.6 times larger than that of the LCC-BTB. In other words, about 1.6 times larger safe operating regions could be obtained for the CCC-BTB compared with the LCC-BTB. The CCC-BTB system resulted in no harmonic instability problem as it has no shunt reactive compensators in the station and the adjoining AC system generates no low anti-resonance frequency points.

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BIOGRAPHY

Hiroo Konishi was born in Tokushima Prefecture, Japan. He received the M.S. degree in electrical engineering from Osaka University, Osaka in 1972. He joined the Hitachi Research Laboratory, Hitachi Ltd., Japan in 1972. Since then he has been working in the development of the control and protection system of power system especially HVDC. He is also interested in power system analysis and simulation. He received the Doctor degree from Osaka University in 1989.

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