Transient performance analysis of Cheju-Haenam HVDC system using PSCAD/EMTDC

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Abstract - This paper deals with dynamic performance of the Cheju - Haenam HVDC systme. The purpose of the study is to verify the control characteristics of the HVDC system and to analyze the dynamic performances by simulation study. Because the HVDC system consists of analogue and digital controller, the simulation is achieved with specification model incorporating nonlinear function. The dynamic performance simulations are performed by PSCAD/EMTDC

Keywords : HVDC system, Dynamic performance, Control model

I. INTRODUCTION

The ± 180 kV 300MW HVDC system in Korea Electric Power Corporation(KEPCO), Completed in 1998, conveys relatively cheap electric power by undersea 100km dc cables from Haenam S/S to Cheju S/S in Cheju island. This 12 pulse bipolar system normally conveys 150 MW which corresponds to 60% of the total load demand in Cheju island. The HVDC system basically adopts inverter operation at Cheju side in which current control is used as the main control and average γ control as the secondary control. At Haenam side where rectifier operation is adopted, voltage control is used as the main control and current control is as the secondary control. The reactive power compensation for inverter side done by condenser bank and synchronous condensers provide transient reactive power compensation, but none is used at rectifier side. Figure 1 presnets the control scheme of the HVDC system.

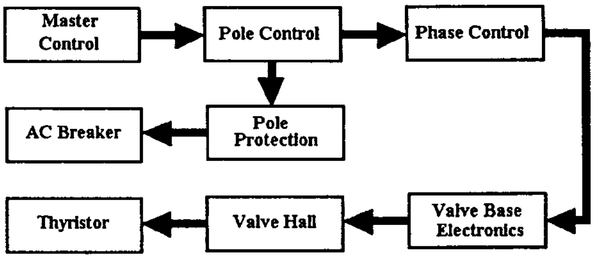


Fig. 1 Cheju-Haenam HVDC system control diagram

The main objective of this paper is to develop a precise simulation model of the Cheju-Hanam HVDC system based on the system dynamic analysis. The model will be used to simulate AC/DC side faults or to study the HVDC controls, and an electromagnetic transients program is more suitable for such studies. The PSCAD/EMTDC which is a well-known electromagnetic transient analysis program is used for this purpose, and the nonlinearity from thyristors and OP-amps is modeled by inserting nonlinear functions to the analog circuits. Simulations are performed on the developed model in order to verify the model and to illustrate its capabilities.

II . Control characteristics of the Cheju-Haenam HVDC system

A. Control Components

a. Master control

The master control is the uppermost control in the HVDC system, and it d+etermines the filter switching mode, the power transfer direction, and the control mode. This control doesn't affect the transient performance of the HVDC system since the time constant of the master control is about a few seconds..

b. Pole Control

Figure 2 shows the block diagram of the pole control. Pole control receives the signal of the control mode and power transfer direction from the master control, which sends the corresponding control signal to the phase control. Detail descriptions of each parts are as follows.

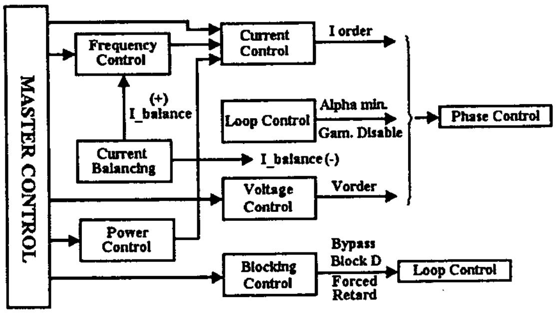


Fig. 2 HVDC system pole controller

0 Frequency Control

The frequency of the Cheju power system is controlled by regulating the power delivered from the dc line when the control mode is on the frequency mode. It corresponds to the governor free operation of the turbine-generator. This control is based on the speed-droop characteristic of the HVDC system, and can be expressed like equation (1).

$$f_r(Hz) = f_d(Hz) - 0.6/150 \cdot P_{dc} \cdot F_{slope}(Drop) \qquad (1)$$

where, $f_r(Hz)$ is the frequency output value, f_d (Hz) is the frequency order value, P_{dc} is the DC power, and $F_{slope}(droop)$ is the speed-droop characteristic of the system.

0 Power Control

The dc line delivers a constant scheduled value of power to the Cheju system when this mode is selected. This control operation can be described as in (2).

$$I_{order} = P_{order} / V_{dc} \qquad (2)$$

where, I_{order} is the current order from the power control, P_{order} is the DC power order, and V_{dc} is the DC voltage value.

0 Current Control

Current control generates the current order value, and is adopted as the main control at Cheju side. Input of the current control depends on the HVDC operation mode: For example, the current order is generated from current control when the HVDC system is in current control mode, and the output value of pole control or frequency control becomes the input for current control.

0 Voltage Control

Voltage control acts as the main control at Haenam side, while it is used as overvoltage limiter at Cheju side.

0 Current Balancing

Current balancing is the function to minimize the current on the neutral line when the HVDC system is in bi-pole operation.

0 Blocking Control

Blocking control issues control signals such as Block D, Bypass and forced retard signals when system failures happen.

Table 1. α Min. values according to Blocking signals

Block D	Forced Retard	Rect./ Inverter	Comm. Fail	Discharge Line	Alpha Min.
Active	X	X	X	X	140 degree
Not Active	Active	X	X	X	140 degree
Not Active	Not Active	Rectifier	X	X	2 degree
Not Active	Not Active	Inverter	X	Active	80 degree
Not Active	Not Active	Inverter	Not Active	Not Active	100 degree
Not Active	Not Active	Inverter	Active	Not Active	70 degree

0 Loop Control - Pole Control

Loop control of the pole control blocks the HVDC system with the blocking control. In the loop control α-min value is regulated to get the fast restoration rate, and the control prevents the failure from being propagated. Table 1 shows the variation of α according to the system failure status.

c. Phase Control

Figure 3 shows the block diagram of phase control in the HVDC system.

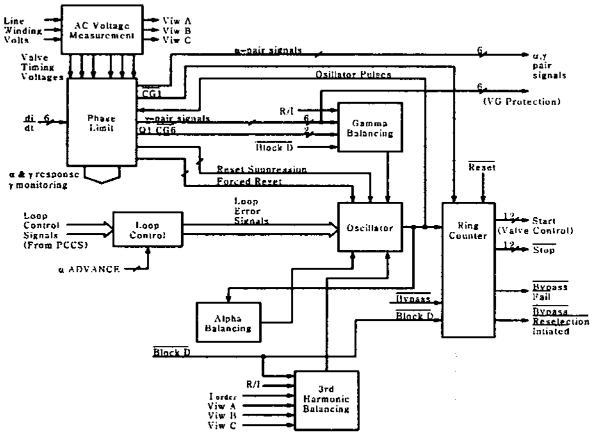


Fig.3 Phase Controller Block diagram

0 AC Voltage Measurement

This card generates Y-△ voltage signal with 30 degree angle difference from 3 phase signal of VT since measurements of phase angle of AC input voltage are required for phase control system.

0 Phase Limit

Phase limit card has the forced firing circuit which makes the firing angle be between 2 and 182 degrees, and calculates the values of α and γ. Permission logic of oscillator receives signal from phase limit.

0 Gamma Balance

The values of three-phase voltage are unbalanced in the strict sense although it is generally assumed to be balanced. Hence, the values of α and γ don't coincide in steady state. Instability of γ control is caused by γ gain ($\sin\alpha/\sin\gamma$), a trend in which $\partial\alpha/\partial\gamma$ becomes positive results in a repeated commutation failure.

0 Alpha Balance

α balance is similar to γ balance, and it is used at rectifier. Unbalance in AC system changes α value, and it enlarges the second harmonic of the AC system. The alpha balancing controls the gating time of the 2 valves at each phase.

0 3th Harmonic Balance

The positive 3^{rd} harmonic voltage from converter transformer is limited by applying the modified signal from oscillator.

0 Loop Control

Loop control in phase control generates error signal by comparing the order value with the measured value. It consists of 8 independent controls where each control has 7 inputs. Four inputs are made of fixed gain and 2 inputs are AC coupled. AC coupling is a kind of differenciater which makes the HVDC system have quick response.

0 Oscillator

Oscillator generates gate pulses in an equal interval. The pulse depends on the maximum value of the error from loop control, and Max./Min. selector or Permission Logic is built using AND/OR logic. It is useful to change the system configuration since the permission logic is implemented by EPROM. Oscillator has the forced reset signal from phase limit and reset suppression signal, and both signals related with permission logic enables gate signals be in the range of 2 ~ 180 degrees.

0 Ring Counter

Ring counter coverts the pulse from oscillator into gating signal, and it has Block D command and free-wheeling command.

B. The Cheju-Haenam HVDC System Performance

Figure 4 shows the control characteristic of the HVDC system between Cheju and Haenam. ABCC'EF represents constant voltage control which is performed the current is less than the rated current (1.0pu). The control mode is changed to current mode when the voltage at the invertor drops or the current is over 1.3 pu.

The line from B to C has the same slope as the YY'Y" line in order to make sure only one operating point is made when the voltage of the invertor drops. This slope is determined by the % impedance of the transformer. The curve C'EF is called as VDCL (Voltage Dependant Current Limit), and it limits current according to the voltage drop due to the failure in AC system.

The curve Y"Y'YXWO represents the characteristic of the invertor. The curve YX corresponds to current control, and the curve YY'Y" to average γ control. The curve XWO is VDCL, and the slope is determined by AC system condition.

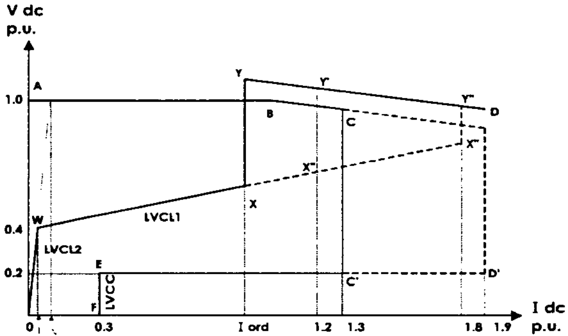


Fig. 4 Cheju-Haenam HVDC characteristics curve

The slope of the curve XWO is different from the curve CEF in convertor, and it helps keep the system stability when SCR of an AC system is small. The selection of the current control or voltage control is performed at the Maximum Value Selector by comparing the output control values from both controls. In invertor there are current control loop and average γ control loop, and the former is used in steady state and the later is used in transient state. This selection is performed in Minimum Value Selector, and the smaller value is chosen by comparing the control output of both control.

III. Analysis of the HVDC System Using PSCAD/EMTDC

A. Need of the Simulation

Every simulation requires system modeling, and the complexity of the model depends on the simulation purpose. For example, power flow analysis asks a model which can represents the system performance in the range of tens of ms or several secs of timestep, but it is not enough for the analysis of transient performance of the system. In this paper, the purpose of the simulation is mainly the analysis of the transient performance of the system, so $50\mu s$ is used for the sampling time. Some components of which time constant is smaller than the sampling times are ignored in the analysis.

PSCAD/EMTDC used in this paper is a popular program to analyze transient and dynamic characteristic in power system. Only HVDC protection system related to control performance need to be considered, and AC/DC differential protection is included in the analysis.

B. Development of AC Equivalent System

AC system is modeled as the Thevenin equivalent system to simulate the transient performance of the HVDC system. AC equivalent system with harmonic generator need to be modeled for analyze harmonic stability. Also, AVRs of generator and synchronous condenser which is connected on the HVDC terminal should be properly modeled since those response is fast and has effects on the operation of the HVDC system. AC system impedance either in the Cheju side or Haenam side is in Table .

2. Base voltage and MVA for the impedance in Table 2 are 154 kV and 100MVA. and SCRs are obtained with the assumption of 150 MW power transfer in the HVDC system. Figure 5 shows one-line diagram of the HVDC system, and consists of harmonic filter, double-tuned filter, synchronous condenser, DC cable, and so on.

Table 2. AC network impedance and SCR

Haenam AC network resistance	0.00675
Haenam AC network reactance	0.04653
Cheju AC network resistance	0.0384
Cheju AC network reactance	0.16174
Haenam AC network SCR	14.1876 ∠-81.96 degree
Cheju AC network SCR	4.010 ∠-76.64 degree

C. Simulation Results

Simulation was performed at the condition where rated voltage of a pole is 180 kV and rated current is 416A. Saturation effects of transformers, harmonic characteristic of AC system, and current unbalance between poles are not considered in this simulation. The faults are supposed to initiate at 1.5 s and have duration of 0.1 s, and only a synchronous condenser operation is considered in the simulation. The HVDC diagram in Figure 5 is based on 300 MW maximum transfer, and reactive compensation amount need to be recalculated in the real case where the power transfer is 150 MW.

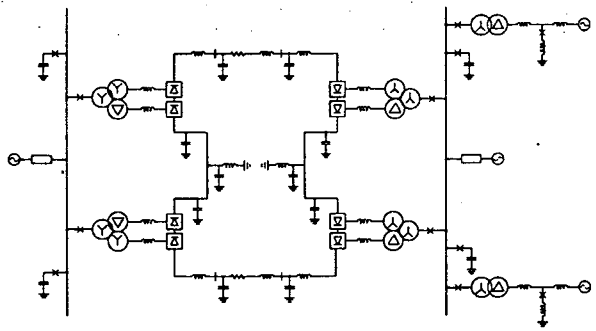


Fig.5 One-line diagram of the HVDC system

● Filters and reactors in inverter side

In order to increase SCR, reactors are used at the secondary side of the transformer of the synchronous condenser. The reactor operation as well as the filter operation depends on the system loading. Switching status of reactors and filters are as follows, and total amount of the reactive compensation is 82.5 Mvar

- 13.75[Mvar](36.7mH) reactor 2 set ON
- 27.5[Mvar}-harmonic filter 2 set ON
- 27.5[Mvar]-double-tuned filter 2 set ON

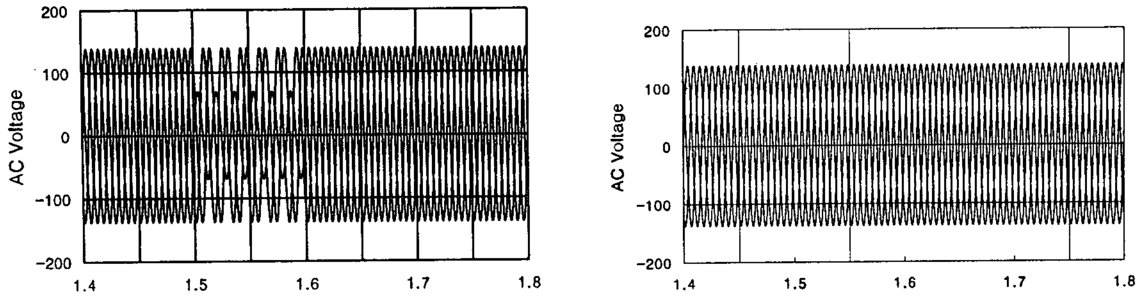
● Filters in rectifier side

Since SCR of the Haenam is high as in Table 2, harmonic filter, double-tuned filter and condenser bank are enough to compensate the rescative power in rectifier side. The following is the status of the filters for 150MW power transfer.

- 27.5[Mvar]-double-tuned filter 2 set ON
- 27.5[Mvar]-harmonic filter 2 set ON

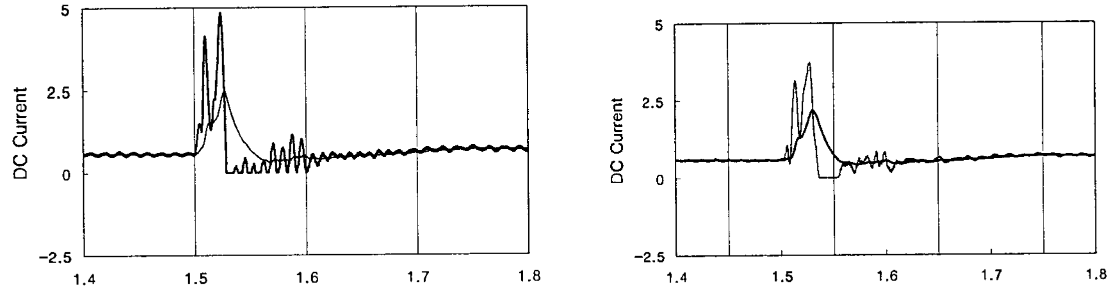
Figure 6 shows the control characteristic of the HVDC system when a fault happens in Cheju AC system. a), b), c), d), e) and f) in Fig. 6 gray and black line represent actual and filtered waveform respectively. Single line to ground fault in AC system at inverter side is the most severe fault to the HVDC system, and 5 kA of transient over-current is observed in fig. 6 (b). In order to reduce the over-current, Haenam side operates as an inverter and Cheju works as a rectifier. Comparing Fig. 6 (b) with 6 (e), large deviation in magnitude and waveform of currents is observed. This is because the cable has large capacitance and inductance. VDCL of Cheju inverter is ramp type not bang-bang type, which makes appear less harmonics in DC voltage of inverter.

IV . Conclusion



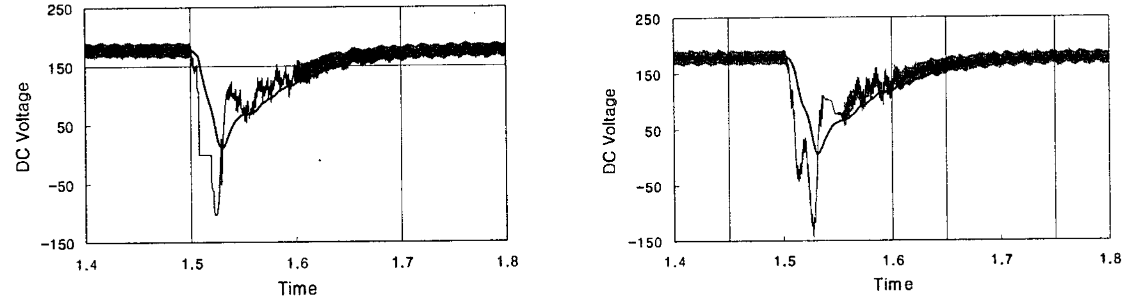
a) Cheju AC voltage

d) Haenam AC voltage



b) Cheju DC current

e) Rectifier DC current



c) Cheju DC voltage

f) Rectifier DC voltage

Fig. 6 Single-phase AC fault at Cheju inverter side

This paper deals with the development of PSCAD/EMTDC model of the Cheju-Hanam HVDC system for the transient analysis. Detail models of pole control, phase control, and protection system were developed and fieldrecord data were used to enhance the accuracy of the model. This model is valuable to analyze characteristics of the HVDC system between Cheju and Haenam, and will be used to study various cases which is related to the HVDC system.

V. References

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