

## Fast Decoupled Power Flow for Power System with High Voltage Direct Current Transmission Line System

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**Abstract: Problem statement:** High voltage direct current transmission line system has been widely applied for control power flow in power system. The power flow analysis was the one of powerful tools by which the power system equipped was analyzed both for planning and operation strategies. **Approach:** This study presented the method to analyze power flow of power system consisted of HVDC system. HVDC was modeled as the complex power injections. The presented complex power injected was incorporated into the existing power flow program based on fast decoupled method. The presented method was tested on the multimachine power system. **Results:** The transmission line loss of the system with and without HVDC was compared. **Conclusion:** From the simulation results, the HVDC can reduce transmission line loss of power system.

**Key words:** Power system, power flow analysis, decoupled power, transmission line loss, multimachine system, proposed method

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### INTRODUCTION

High Voltage Direct Current (HVDC) transmission line system is getting more and more popular because of lower investment cost in long distance, lower losses, asynchronous interconnection between power systems, better controllable power flow compared with Alternating Current (AC) system (Al-Abdulaziz *et al.*, 2006; Lu *et al.*, 2006; Sun *et al.*, 2008). The great important role of power flow analysis is to determine the operating point of the existing, study in planning the future expansion and evaluate the best operating point of power system (Ahmed *et al.*, 2008; Al-Rawi *et al.*, 2007; Augusto *et al.*, 2008; Noor *et al.*, 2008).

The objective of power flow analysis of the system equipped with HVDC system is to solve operating point both AC and HVDC system. In the performing power flow calculation of AC system on the nodal iterative method, two AC variables are specified while the remaining two AC variables are solved iteratively. There are many methods of power flow analysis (Parry and Gangatharan, 2005; Federico, 2009). The fast decoupled power flow provides rapid solution for power system with low resistance and susceptance ratio (Avakian *et al.*, 2006). HVDC transmission line system is based on advanced power electronic technology. The parameter in HVDC side is the DC quantities. It is simultaneously solved the AC and DC parameters.

This study presents the power flow analysis of power system equipped with HVDC system. The

presented mathematical model of HVDC system is incorporated into AC power flow analysis based on fast decoupled method. The simulation results are tested on multimachine system and compared with various cases.

### MATERIALS AND METHODS

AC fast decoupled power flow: The fast decoupled power flow equations of solving unknown parameters of Voltage magnitude (V) and angle ( $\delta$ ) are given by:

$$\Delta\delta = -[B']^{-1} \frac{\Delta P}{V} \quad (1)$$

$$\Delta V = -[B'']^{-1} \frac{\Delta Q}{V} \quad (2)$$

Here B' and B'' are the imaginary part of bus admittance. P and Q are the active and reactive power injection at AC system.

**HVDC model:** Figure 1a shows the schematic diagram of HVDC system. The equivalent circuit of Fig. 1a is shown in Fig. 1b. The subscripts represent the sending quantities end and the subscripts 'r' represents the receiving end parameters. The converter can be represented by the variable DC voltage source ( $V_d$ ) and constant resistance ( $R_c$ ). The DC transmission line is represented by constant resistance  $R_L$ .

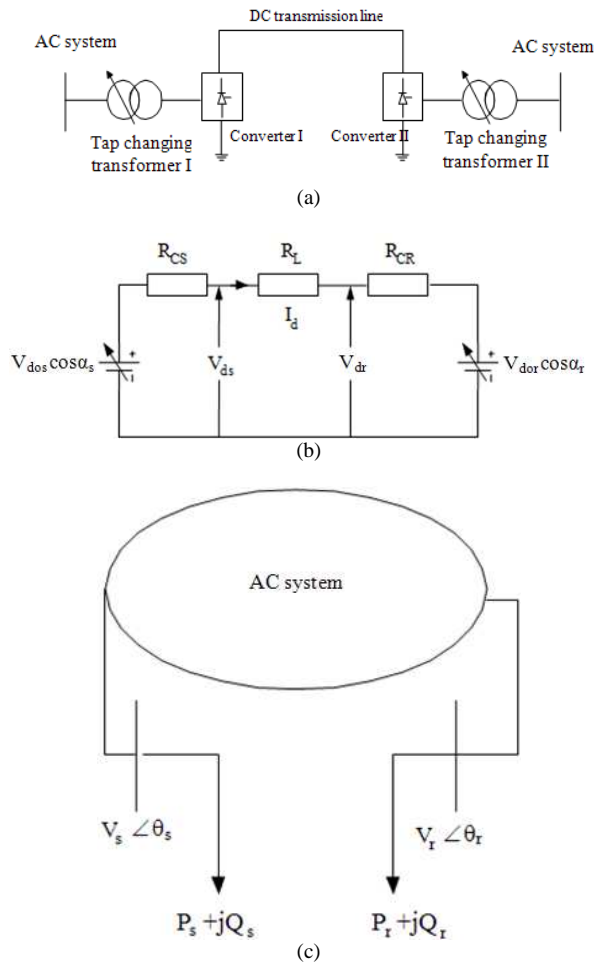


Fig. 1: Configuration of power system with HVDC transmission line system; (a) HVDC system; (b) Equivalent of HVDC system; (c) Successive HVDC model in power system

The ideal no load direct voltage is given by:

$$V_{dos} = (V_{ds} + I_d R_{C1}) / \cos \alpha \quad (3)$$

$$V_{dor} = (V_{dr} - I_d R_{C2}) / \cos \gamma \quad (4)$$

Here  $\alpha$  and  $\gamma$  are the ignition angle of converter I and converter II, respectively.

The average DC output voltage is given by:

$$V_{ds} = V_{dr} + I_d R_L \quad (5)$$

Here,  $I_d$  is the DC line current.

The power factor  $\phi$ , fundamental line current lags the line voltage is written by:

$$\cos \phi_s = V_{ds} / V_{dos} \quad (6)$$

$$\cos \phi_r = V_{dr} / V_{dor} \quad (7)$$

The real and reactive powers at the sending and receiving end are:

$$P_s = V_s I_d \quad (8)$$

$$Q_s = P_s \tan \phi_s \quad (9)$$

$$P_r = V_r I_d \quad (10)$$

$$Q_r = P_r \tan \phi_r \quad (11)$$

AC-HVDC fast decoupled power flow: The voltage magnitude, voltage angle and power flow of the AC-HVDC interconnecting equations must be coincident at the interconnecting point of the AC-HVDC systems. The active and reactive power and the bus voltages to be supplied from the AC system are calculated using the specified initial value of DC system. The derived active and reactive power are incorporate into AC fast decoupled power to evaluate the unknown parameter at sending and receiving end bus as shown in Fig. 1c and given by:

$$\Delta \delta_s = -[B]^{-1} \frac{\Delta P_s}{V_s} \quad (12)$$

$$\Delta \delta_r = -[B]^{-1} \frac{\Delta P_r}{V_r} \quad (13)$$

$$\Delta V_s = -[B^*]^{-1} \frac{\Delta Q_s}{V_s} \quad (14)$$

$$\Delta V_r = -[B^*]^{-1} \frac{\Delta Q_r}{V_r} \quad (15)$$

The procedure is repeated until all the relations interconnecting the AC-HVDC quantities are satisfied with sufficiently small errors.

## RESULTS

The proposed method of fast decoupled power flow of power system with HVDC system is tested on the multimachine system as shown in Fig. 2. The HVDC system is equipped between bus 10 and bus 12. The power system consists of 5 generators 18 buses. The proposed method achieved the output of power flow analysis. Table 1 shows the transmission line losses of the power system without HVDC system and with HVDC system.

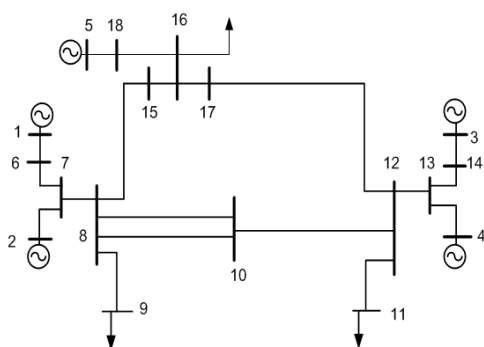


Fig. 2: Configuration of tested power system

Table 1: Transmission line losses of power system without HVDC and with HVDC

Line (between buses)	Without HVDC		With HVDC	
	P	Q	P	Q
1-6	0.000	1.090	0.0000	1.066
6-7	0.160	1.600	0.1590	1.555
2-7	0.000	0.940	0.0000	0.931
7-8	0.230	2.360	0.2340	2.318
8-10	0.034	-0.030	0.0400	0.017
8-9	0.000	0.512	0.0000	0.509
10-12	0.038	0.199	0.0020	-0.180
11-12	0.000	1.240	0.0000	1.110
12-13	0.239	2.380	0.2050	2.030
13-4	0.131	1.188	0.1307	1.266
13-14	0.131	1.266	0.0000	0.789
3-14	0.000	0.872	0.0000	0.789
8-15	0.116	0.973	0.0860	0.678
15-16	0.000	0.150	0.0000	0.109
16-17	0.000	0.004	0.0000	0.010
17-12	0.010	-0.160	0.0190	-0.110
16-18	0.046	0.095	0.0460	0.091
5-18	0.000	0.113	0.0000	0.113
Total loss	1.020	14.800	0.9180	13.220

### DISCUSSION

It can be seen from the simulation results that active and reactive power loss of power system without HVDC are around 1.02 and 14.80 p.u., respectively. However, with HVDC system, the active and reactive power loss is decreased to 0.918 and 13.22 p.u., respectively.

### CONCLUSION

This study proposed the fast decoupled power flow analysis of power system with HVDC system. The HVDC power flow is specified and then the derived active and reactive power are incorporate into AC fast decoupled power to evaluate the unknown parameter at sending and receiving end.

The proposed method was tested on the multimachine system. It was found that the proposed

method achieved the output of power flow analysis. It is shown from simulation results that HVDC not only can control power flow through the transmission line but also can decrease the transmission line loss.

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