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LOSS ANALYSIS OF HYBRID AC/DC DISTRIBUTION NETWORK CONSIDERING VSC CONTROL STRATEGY

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ABSTRACT

In recent years, due to the development of DC load and large-scale grid-connected distributed generations (DGs), the hybrid AC/DC distribution network has drawn more attentions. This paper studies the influence of voltage source converter (VSC) control strategy on hybrid AC/DC distribution network loss. Firstly, the steady-state model of VSC is established. Then, the calculation method of hybrid AC/DC distribution network loss is given based on the AC/DC distribution network power flow calculation method. Finally, the control strategy and output power of VSC are determined by genetic algorithm (GA) with the goal of loss minimization. A typical AC/DC distribution network is used to analyze the influence of the VSC control strategies to hybrid AC/DC distribution network loss. The simulation result proves the effectiveness of the proposed minimization algorithm.

Keywords: hybrid AC/DC distribution network; power flow calculation; loss minimization; converter control

1. INTRODUCTION

The hybrid AC/DC distribution networks are becoming more practical and cost-effective for the development of high penetration of DC distributed generations (DGs) and DC electronic loads. Compared with the traditional distribution network, the hybrid AC/DC distribution network has the advantages of high hosting capability of distributed energy, favorable flexible load access and flexible control modes. Hybrid AC/DC distribution network based on flexible DC technology has better properties in terms of reliability, flexibility, economy and safety. Therefore, it becomes an important direction for the development of distribution network.

Minimizing loss is an important for the economical of AC/DC distribution system [1]. In hybrid AC/DC distribution network, the converter valve is the key equipment for realizing the power transmission between the AC system and the DC system. In [2] a power flow calculation method for multi-terminal voltage source converter direct current (VSC-MTDC) systems are analyzed for different types of dc voltage control techniques and the weaknesses of present methods are addressed. In [3] general power flow model of VSC is established and augmented Jacobi matrix is used to represent the AC system and DC system. In this model, the VSC equations contain the AC and DC system model while considering the VSC loss.

The steady-state model and loss calculation for voltage source converter (VSC) has been studied in many aspects. However, the existing research results mostly focus on the loss calculation of the converter itself. There are few researches on the analysis of the influence of converter power and control strategy to the power losses of hybrid AC/DC distribution network. This paper analyzed the influence of VSC control strategy and out power to AC/DC distribution network loss. Firstly, the steady-state model of VSC is established. Then, the calculation method of hybrid AC/DC distribution network loss is given based on power flow calculation method of the hybrid AC/DC distribution network. Finally, the control strategy and output power of VSC are determined by genetic algorithm (GA) with the goal of loss minimization.

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2. HYBRID AC/DC DISTRIBUTION NETWORK LOSS CALCULATION MODEL

2.1 AC side current balance equation

The basic equation for power flow calculation on the AC side can be expressed as：

$$\begin{cases} P_{aci} = U_i \sum_{j \in i} U_j (G_{ij} cos\theta_{ij} + B_{ij} sin\theta_{ij}) \\ Q_{aci} = U_i \sum_{j \in i} U_j (G_{ij} sin\theta_{ij} - B_{ij} cos\theta_{ij}) \end{cases} \tag{1}$$

where P_{aci} and Q_{aci} represent the injected active power and reactive power of node *i*, respectively; $j \in i$ represents all nodes adjacent to *i* and include node *i*; G_{ij} and B_{ij} are the real and imaginary parts of admittance matrix element Y_{ij}, respectively. The active loss of the line is obtained by the following formula*:*

$$P_{AC\text{-}loss} = \sum_{i=1}^{N} R_i \frac{P_{aci}^2 \text{-} Q_{aci}^2}{U_i^2} \tag{2}$$

where $P_{AC\text{-}loss}$ represents the AC distribution network loss, *N* represents the number of branch of the AC grid; r_i represents the resistance value of branch *i*.

2.2 VSC steady-state model

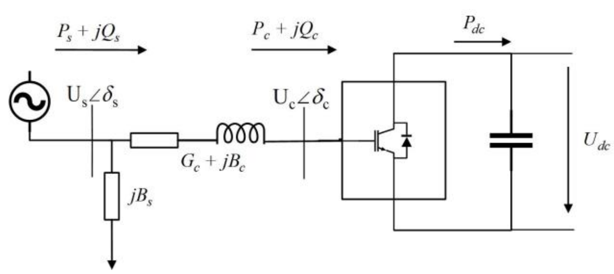

Fig 1 VSC steady-state model

Fig 1 shows the VSC steady-state model. P_s and Q_s represent the active power and reactive power of VSC converter in the AC bus; U_s and δ_s are the amplitude and phase angle of the voltage at the common connection point; Y_c is the admittance of the converter; jB_s represents the inductive reactance of the port shunt capacitor, U_c, δ_c represents the voltage amplitude and phase angle of the output of the converter AC side, P_{dc} is the DC side injected power, U_{dc} is the DC side output voltage of the converter. Use the arrow in Fig 1 as the positive direction of power, the following relationship can be obtained：

$$\begin{cases} P_s = U_s^2 G_c - U_s U_c (G_c \cos\delta + B_c \sin\delta) \\ Q_s = -(B_c + B_s) U_s^2 - U_s U_c (G_c \sin\delta - B_c \cos\delta) \end{cases} \tag{3}$$

$$P_{dc} = P_s \text{-} P_z \text{-} P_{vsc\text{-}loss} \tag{4}$$

In the above formula, δ represent the phase angle difference between the voltage U_s and the voltage U_c. P_z represents the loss of equivalent admittance Y_c of VSC filter and can be expressed as

$$P_z = I_c^2 \cdot Y_c \tag{5}$$

$$I_c = \frac{\sqrt{P_s^2 + Q_s^2}}{\sqrt{3} U_s} \tag{6}$$

The internal loss model of the VSC converter can be fitted by the AC side current I_c, the internal loss of the converter and the current value I_c of the AC side in a quadratic function relationship, which is shown by (7).

$$P_{vsc\text{-}loss} = aI_c^2 + bI_c + c \tag{7}$$

where $P_{vsc\text{-}loss}$ represents VSC commutation Internal loss of the device; *a*, *b*, *c* represents the converter loss coefficient of the VSC [4].

2.3 DC side current balance equation

The injection current $I_{dc,m}$ of the DC side bus *m* can be obtained by the following formula:

$$I_{dc,m} = \rho \sum_{j=1}^{N} Y_{dc,mn} (U_{dc,m} - U_{dc,n}) \quad m = 1,2,\cdots,N \tag{8}$$

where $I_{dc.m}$ represents the current of the DC bus *m*, *ρ* represents the number of pole in the DC system, $Y_{dc.mn}$ represents the admittance matrix of the DC node, $U_{dc,m}$ and $U_{dc,n}$ represents the voltage of the nodes *m* and *n*. Each node of the DC distribution network needs to provide or calculate only the active power *P* and the voltage *U*. The general form of the *m*-th node injection power of a DC distribution network containing n nodes is:

$$P_{dc,m} = \rho U_{dc,m} \sum_{j=1}^{N} Y_{dc,mn} U_{dc,n} \tag{9}$$

The injection power of the *m*-th DC bus is represented as:

$$P_{dcm} = P_{VSC,m} + P_{DG,m} - P_{dm} \tag{10}$$

where $P_{VSC,m}$ represents the injection power of converter; $P_{DG,m}$ represents the power of node *i* to access the distributed generation, and P_{dm} is the DC load power of node *i* access.

$$P_{DC\text{-}loss} = \sum_{m=1}^{N} R_m I_{dcm}^2 \tag{11}$$

where $P_{DC\text{-}loss}$ represents the DC distribution network loss. *N* represents the number of branch, I_{dcm} represents the current of branch *m*, r_m represents the resistance value of branch *m.*

2.4 Hybrid AC/DC distribution network loss calculation

The power flow method is used to calculate the loss of distribution network because it has high calculation accuracy and is more suitable for theoretical analysis. In this paper, the alternating iterative method is used to calculate the power flow and loss of hybrid AC/DC distribution network [5,6]. Hybrid AC/DC distribution network loss calculation process, as shown in Fig 2.

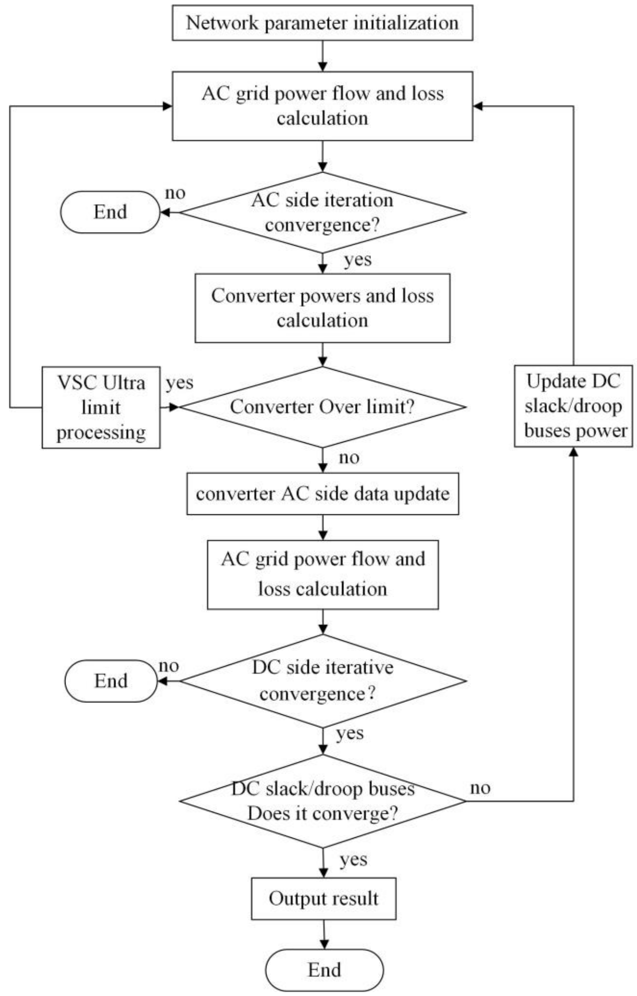

Fig 2 Hybrid AC/DC distribution network loss calculation flow chart

3. AC/DC DISTRIBUTION NETWORK LOSS OPTIMIZATION

The GA is used to optimize the control strategy and the output power of VSC to reduce the power losses of hybrid AC/DC distribution network.

3.1 Objective function

The objective is to minimize the power losses of the hybrid AC/DC distribution network:

$$\min P_{loss} = P_{AC-loss} + P_{vsc-loss} + P_{DC-loss} \tag{12}$$

3.2 Constraint condition

Considering the voltage limit and capacity limitation of the VSC, the following constraints need to be satisfied:

$$\begin{cases} U_{min} \le U_{vsc,i} \le U_{max} \\ P_{min} \le P_{vsc,i} \le P_{max} \end{cases} \tag{13}$$

Taking into account the line transmission limit, the line allows the maximum current I_{Limax} to have the following restrictions:

$$-I_{Limax} \le I_{Li} \le I_{Limax} \tag{14}$$

3.3 Genetic algorithm

This paper proposes the loss minimization method using the GA in [7]. Decimal coding method is applied and the reciprocal of the active power loss is taken as the fitness of a chromosome. The larger the power loss is, the less the fitness is. The roulette wheel selection algorithm, single-point mutation strategy and multi-point crossing strategy are used in the GA.

4. CASE ANALYSIS

In this paper, the IEEE33 bus distribution network base hybrid AC/DC distribution network is used for simulation, shown in Fig 3. The distribution network loss and VSC loss calculation is carried on matlab2016a platform. The DC side voltage of the converter station is 10kV, the voltage range is set to [0.9p.u., 1.1p.u.]. The loss factor of VSC are a=0.01503 and b=0.887. The output power of DG is 1.1 MW.

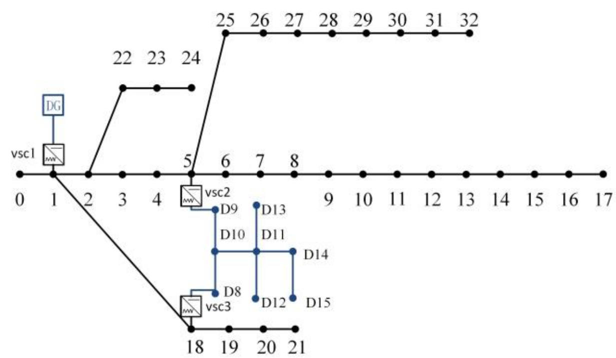

Fig 3 Transformed IEEE33-bus test system

According to Fig 4 and Fig 5 showing the distribution network loss line diagram under master-slave control strategy and droop control strategy, the change of converter power will have a considerable impact on system loss. As the input power of VSC2 increases, the loss on the AC side increases monotonically, and the converter loss and DC side loss decrease first and then rise. The total loss first decreases and then starts to rise at the inflection point. When the converter adopts the droop control strategy, the AC side loss and the converter loss are similar to those of the master-slave control strategy, but there is a certain difference in the DC side loss of the system.

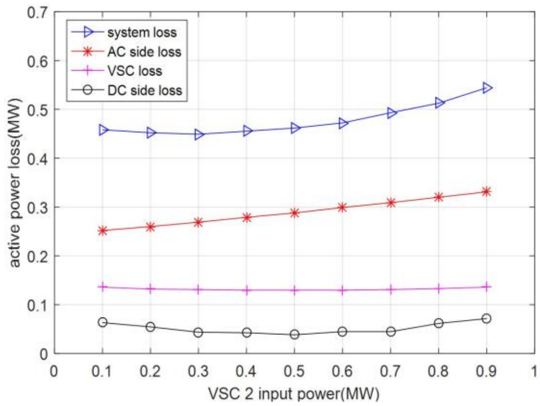

Fig 4 Distribution network loss line diagram under master-slave control strategy

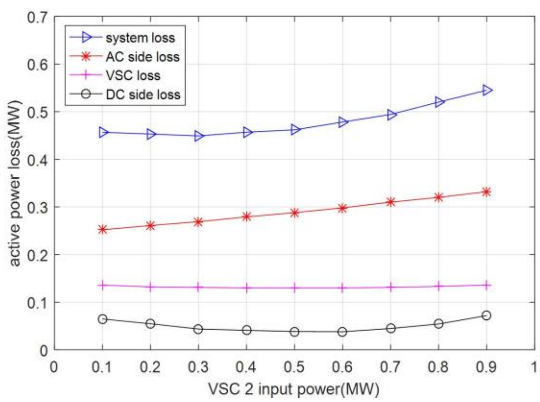

Fig 5 Distribution network loss line diagram under droop control strategy

Tab. 4 shows the optimized results of converter operating power through GA. As can be seen from Table 4, when the master-slave control strategy is adopted in the system, the output power from the converter valve VSC2 is 0.288MW, the network total loss is 0.4618MW. Nodal voltages have not exceeded the limit. When the droop control strategy is adopted in the system, the output power from the converter valve VSC2 is 0.267MW, the network loss is 0.46180MW. $V_{DC\text{-}min}$ represents the minimum voltage amplitude on the DC side at bus D15, $V_{AC\text{-}min}$ represents the minimum voltage amplitude on the AC side at bus 17.

Tab. 4 Optimized converter power and loss

Control Strategy	VSC2 (MW)	VSC3 (MW)	Power loss(MW)	$V_{DC\text{-}min}$ (p.u.)	$V_{AC\text{-}min}$ (p.u.)
Master-slave	0.45	--	0.46180	0.99045	0.9006
Master-slave	0.288	--	0.44565	0.98910	0.9033
Droop	0.45	0.45	0.46180	0.99045	0.9004
Droop	0.267	0.633	0.44548	0.98893	0.9031

5. CONCLUSIONS

In this paper, a method for calculating and optimizing the loss of AC/DC distribution network, considering the converter control strategy and multi-dimensional constraints, is proposed. The calculation method of hybrid AC/DC distribution network loss is presented based on the hybrid AC/DC distribution network power flow calculation method. The control strategy and the output power of VSC are determined by GA with the goal of loss minimization. The proposed method and strategy are applied in the simulation system, the influence of VSC control strategy on hybrid AC/DC distribution network loss is tested, and the result proves and the effectiveness of the proposed minimization algorithm.

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