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RELIABILITY EVALUATION OF AC/DC HYBRID DISTRIBUTION NETWORKS WITH OPERATION CHARACTERISTICS OF VSC CONVERTERS CONSIDERED

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ABSTRACT

The uncertainties of outputs of distributed generators (DGs) put higher requirements on the reliability of distribution networks. Meanwhile, with the widely integrated of DGs, AC/DC hybrid distibution network is becoming a general trend. In this paper, an evaluation analysis method is proposed to evaluate the reliability of AC/DC hybrid distribution networks with high integration of DGs. The optimal load shedding model with VSCs is presented. By non-sequential Monte Carlo simulation, a framework of evaluating AC/DC hybrid distribution networks is presented. Case studies are performed on the modified IEEE 123-node network. Finally, by comparing with a modiefied AC distribution network, the reliability improvement brought by DC network is verified.

Keywords: reliability evaluation; AC/DC hybrid distribution networks; distributed generators; optimal load shedding model

NONMENCLATURE

Abbreviations	
DG	Distributed Generator
VSC	Voltage Source Converter
EENS	Expected Energy Not Supplied
SAIFI	System Average Interruption Frequency Index
SAIDI	System Average Interruption Duration Index
Symbols	
N_C	Number of components in distribution networks
$P_{shed,j}$	Shed active load of node *j*
N_L	Number of loads in distribution networks
P_{ij} / Q_{ij}	Active/reactive power flow from node *i* to node *j*
P_i / Q_i	Sum of active/reactive power injected into node *i*
r_{ij} / x_{ij}	Resist/reactance of branch *ij*
Ω_{AC}	Set of AC nodes
$Q_{shed,j}$	Shed reactive load of node *j*
P_{VSC} / Q_{VSC}	Active/reactive power through VSC
S_{VSC}	Capacity of VSC
$P_{VSC,AC} / P_{VSC,DC}$	Active power from AC/DC side of VSC
U^{min} / U^{max}	Lower and upper bounds of node voltage
I^{max}	Upper bound of branch current

1. INTRODUCTION

With the development of DC transmission and power electronics technologies, DC devices are widely used in distribution networks. AC/DC hybrid distibution network is becoming a general trend. Distributed generators (DGs) are widely integrated into AC/DC hybrid distribution networks, which bring new challenge to the reliable operation of distribution networks [1].

Previous studies have investigated the evaluation method of reliability for distribution networks. A reliability evaluation algorithm for distribution network with microgrid is proposed in [2]. Based on generalized capacity outage table, an evaluation method for DGs in

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active distribution network is presented in [3]. Using sequential Monte Carlo simulation, an evaluation method for DC distribution networks is proposed in [4]. With the widely application of AC/DC hybrid distribution technology, the existing method of evaluating reliability of distribution networks will no longer apply.

In this paper, an evaluation analysis method based on non-sequential Monte Carlo simulation is proposed to evaluate the reliability of AC/DC hybrid distribution networks. The reliability model of AC/DC components are proposed firstly. Secondly, the control strategies of voltage source converters (VSCs) under different fault scenarios is considered. Finally, the optimal load shedding model with VSCs operation mode optimization considered is presented.

2. RELIABILITY EVALUATION MODEL FOR AC/DC HYBRID DISTRIBUTION NETWORKS

2.1 Reliability evaluation model for AC and DC components

The reliability of each component in AC/DC hybrid distribution networks affects the reliability of the entire network. In this paper, the components are divided into two parts: basic components and voltage source converter (VSC). Basic components include AC transformers, AC/DC lines and AC/DC buses. The reliability models of basic components can be expressed as determined reliability parameters, which can be obtained from historical data.

Voltage source converters (VSCs) are widely used in AC/DC distribution networks. As can be seen in Fig. 1, five parts consist of VSC: 1) AC equipment (AC-E); 2) Converter valve (V); 3) Control and protection system (C&P); 4) DC equipment (DC-E); 5) Others (O).

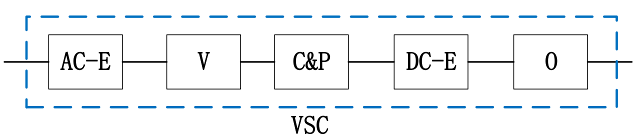

Fig.1 Structure of VSC

The reliability parameters of each parts can be derived from high voltage converter station in transmission grid [5]. Then the reliability parameters of VSC can be obtained from the reliability calculation formula of the series model.

2.2 Reliability Evaluation process

Based on non-sequential Monte Carlo simulation, the process of reliability evaluation of AC/DC hybrid distribution networks with high integration of DGs can be expressed as follows, also is shown in Fig. 2.

1) An annual power curve is established based on historical data of DGs and loads.

2) Status of DGs and loads are obtained by the non-sequential Monte Carlo simulation.

3) The control strategies of VSCs are changed under different fault scenarios.

4) By AC/DC power flow calculation, the operation scenarios of distribution networks can be obtained.

5) Under the scenarios that exists line overload or voltage violation, the minimum load shedding are obtained by solving the load shedding model with control parameter optimization of VSCs.

6) The reliability indexes are calculated and updated.

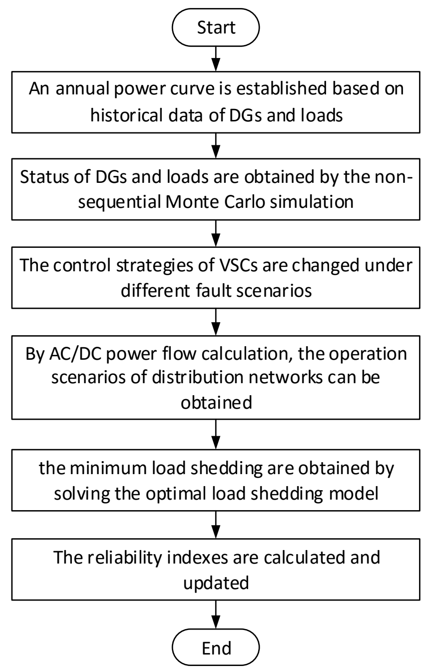

Fig 2 Flow chart of reliability evaluation of AC/DC hybrid distribution networks with high penetration of DGs

2.3 Load shedding with control parameter optimization of VSCs

If there is line overload or voltage violation in AC/DC hybrid distribution networks, loads are needed to be shed to keep distribution network reliable. The minimum load shedding model can be expressed as follows:

1) Objective function

$$\min \quad f(x) = \sum_{j=1}^{N_L} P_{\text{shed},j} \tag{1}$$

2) Operational constraints

- Power flow constraints of AC network

$$\sum_{ji \in \Omega_{AC}} \left(P_{ji} - r_{ji} I_{ji}^2 \right) + P_i - P_{\text{shed},i} = \sum_{ik \in \Omega_{AC}} P_{ik} \tag{2}$$

$$\sum_{ji\in\Omega_{AC}}\left(Q_{ji}-x_{ji}I_{ji}^2\right)+Q_i\text{-}Q_{shed,i}=\sum_{ik\in\Omega_{AC}}Q_{ik} \tag{3}$$

$$U_i^2-U_j^2+\left(r_{ij}^2+x_{ij}^2\right)I_{ij}^2-2\left(r_{ij}P_{ij}+x_{ij}Q_{ij}\right)=0 \tag{4}$$

$$I_{ij}^2U_i^2=P_{ij}^2+Q_{ij}^2 \tag{5}$$

- Power flow constraints of DC network

$$P_{ij}=U_i\sum_{j\in\Omega_{DC}}U_j/r_{ij} \tag{6}$$

- Load shedding constraint

In load shedding process, the power factor is needed to be contained, which can be expressed as equation (7).

$$P_i/Q_i=P_{shed,i}/Q_{shed,i} \tag{7}$$

- Operational constraints of VSC

The active power and reactive power of VSC should be subject to the following constraints.

$$P_{VSC}^2+Q_{VSC}^2\le S_{VSC}^2 \tag{8}$$

$$P_{VSC,DC}=-\left(P_{VSC,AC}+\alpha\left|P_{VSC,AC}\right|\right) \tag{9}$$

α represents the loss factor of VSC.

- Secure operation constraints

$$\left(U^{\min}\right)^2\le U_i^2\le\left(U^{\max}\right)^2 \tag{10}$$

$$I_{ij}^2\le\left(I^{\max}\right)^2 \tag{11}$$

3. CASE STUDY

The modified IEEE 123-node distribution network is shown in Fig. 3. The maximum load of distribution network is set as 22 MW. Five DGs with the capacities of 2 MW are integrated into the networks. The capacities of converters are set as 5 MW. The sampling number of Monte Carlo simulation is set as 10^6. The reliability parameters of AC/DC components can be obtained in IEEE 2007 reliability data [6], as can be seen in Tab. 1. Three reliability indexes are used in this paper, which are EENS, SAIFI, and SAIDI. The switching time of tie switch is set as 0.5 h.

Tab 1 Reliability parameters of AC/DC components

Component	Fault rate (occ./year)	Repair time (h)	Replacement time (h)
Transformer	0.015	200	10
VSC	2.6828	4.7193	/
Line	0.04 /km	30	/
Buses	0.001	2	/

In order to analyze the impact of DC components on reliability, an AC distribution network is set up as a comparison case based on the above AC/DC distribution network. DC lines are replaced by AC lines while VSCs are replaced by tie switches, as can be seen in Fig. 4.

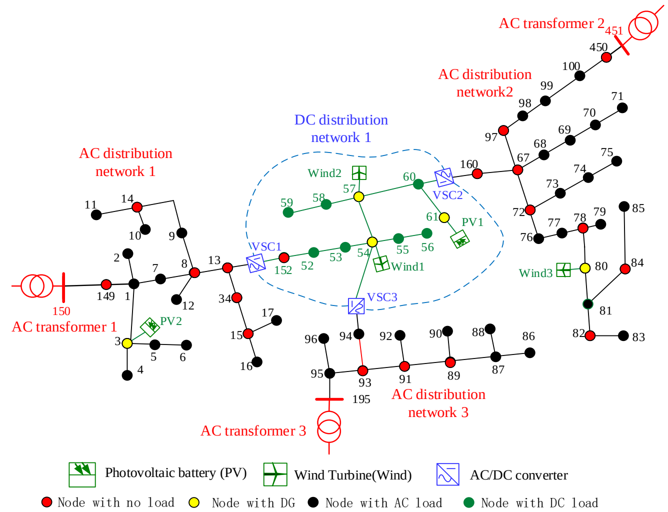

Fig 3 Structure of the AC/DC distribution network

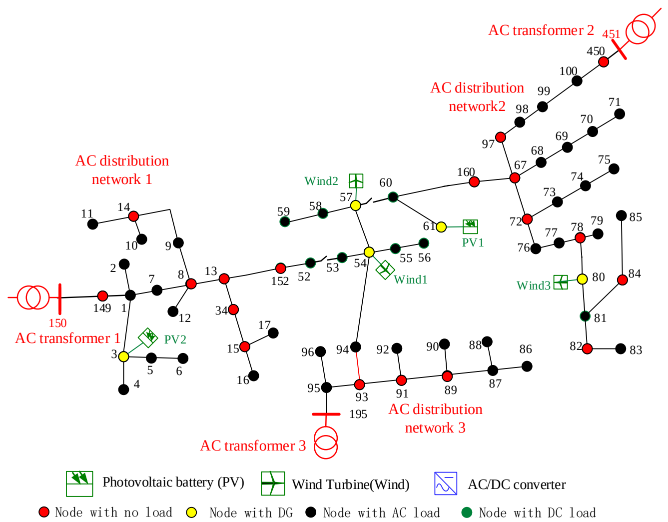

Fig 4 Structure of the AC distribution network

Two scenarios are set to study the characteristics of AC/DC distribution network.

Scenario I: The loads in the network are all the same.

Scenario II: The loads in AC distribution network 2 are designated as resident loads, while the rest loads as industrial and commercial loads.

1) Scenario I

Results are shown in Tab. 2. It can be seen from Tab. 2 that EENS and SAIDI of the AC/DC hybrid distribution network are lower than the AC distribution network, so its reliability is higher than that of AC distribution network.

Due to the higher fault rate of VSC, the SAIFI of AC/DC network is a little higher than AC network. On the contrary, the SAIDI of AC/DC network is lower than AC network instead. It's because that the AC/DC network have faster adjustment speed while it takes more time in operation of tie switches in AC distribution network.

Tab 2 Reliability indexes in Scenario I

	EENS MWh/Year	SAIFI Times/Year	SAIDI Hours/Year
AC network	9.2131	0.0816	4.0802
AC/DC network	7.8075	0.0978	2.9398

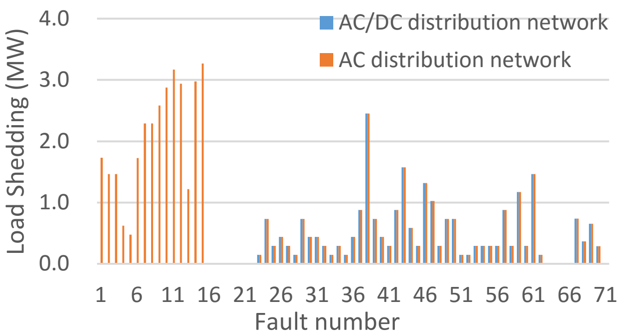

Fig 5 Comparison of load shedding

Furthermore, N-1 check of two networks is used to analyze the reliability improvement of EENS in AC/DC network. Results can be seen from Fig. 5. Apart from the fault scenario in which the load sheddings are the same in two networks, in fault scenario (1-15), the load shedding of AC distribution network is much higher than the AC/DC network. There are two main reasons: 1) in AC/DC network, VSCs have voltage support ability to the disribution network under extreme fault scenarios; 2) in AC/DC network, each AC network may has multiple backup sources by connection of DC network, thus has continuous power control capability, effectively reducing the power loss area.

2) Scenario II

For the resident loads, the peaks of loads exist at night. On the contrary, the peaks of industrial and commercial loads exist at daytime, which lead to changes in system operation mode. Results are shown in Tab. 3

Tab 3 Reliability indexes in Scenario II

	EENS MWh/Year	SAIFI Times/Year	SAIDI Hours/Year
AC network	10.5114	0.0944	4.7217
AC/DC network	7.9096	0.0978	2.9398

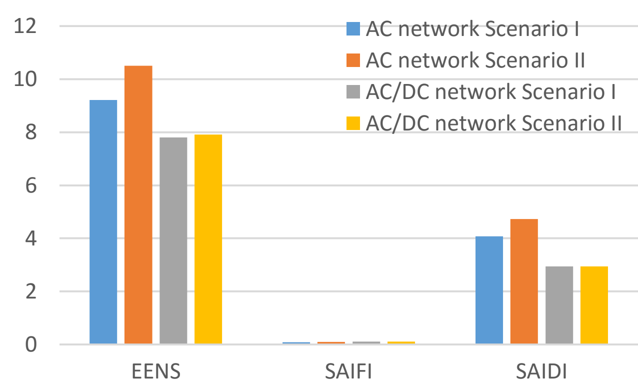

Fig 6 Changes of reliability indexes in different scenarios

Compared with scenario I, the changes of reliability indexes for two system are shown in Fig. 6. For AC/DC network, the reliability indexes are nearly the same in two scenarios. But for AC network, the reliability indexes in scenario II are all higher than those in scenario I.

The result shows that when there are different kinds of loads in the network, the AC/DC distribution network can greatly adapt to the changes of load distribution due to the flexibility and controllability of its operating mode, thereby improving the reliability of the system.

4. CONCLUSION

The uncertainties of DG outputs and the application of DC devices make conventional reliability evaluation method no longer apply. In this paper, an optimal load-shedding model is presented. The reliability evaluation method for AC/DC hybrid distribution network is realized by non-sequential Monte Carlo method. The method proposed in this paper considers the regulation characteristics of VSC and fully adapts to the new operational characteristics presented by AC/DC hybrid distribution networks. Case studies are performed on the modified IEEE 123-node network. By comparing with a modiefied AC distribution network, the reliability improvement brought by DC network is verified.

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REFERENCE

[1] Kwasinski A. Quantitative evaluation of DC micro grids availability: effects of system architecture and converter topology design choices. IEEE Trans Power Electr 2011; 26: 835-51.

[2] Liang H, Cheng L, Liu S. Monte Carlo simulation based reliability evaluation of distribution system containing micro grids. Power Syst Tech 2011; 35: 76-81.

[3] Bie Z, Zhang P, Li G. Reliability Evaluation of active distribution systems including microgrids. IEEE Trans on Power Syst 2012; 27: 2342-50.

[4] Liang D, Qin C, Wang S. Reliability evaluation of DC distribution power network. China international Conference on Electricity Distribution 2018; 654-8.

[5] Zeng J, Xu X, Zhao Y. AC/DC distribution network reliability comparison. Power System Technology 2014; 38: 2582-9.

[6] IEEE Std 493-2007. IEEE recommended practice for the design of reliable industrial and commercial power systems. USA 2007.