RELIABILITY EVALUATION OF DISTRIBUTION NETWORK CONSIDERING CONTROLLABLE DISTRIBUTED GENERATION, BATTERY SWAPPING STATION AND CONTROLLABLE SWITCHES

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ABSTRACT

Distributed generation (DG) and battery swapping station (BSS) access to the distribution network has brought impact to the reliability of distribution network. The method to assess the reliability of power distribution network with DG and BSS is proposed in this paper. First, according to the island formation strategy with DG, the case of island unable to form due to DG power shortage is analysed.Then, considering the energy storage characteristics of BSS while DG power shortage, the island formation strategy with DG and BSS is proposed and the island formation probability can be calculated. Finally, the correctness of algorithm in this paper is verified by using the IEEE 3 feeder distribution system.

INTRODUCTION

The use of DG is of great significance to alleviate the energy crisis and improve the environment. However, with a large number of DG and BSS (Battery Swapping Station) access to the distribution network, it has changed the radiant power supply mode of the traditional distribution network, bringing new challenges to the reliability evaluation of distribution network. For the distribution network with DG, the reliability of island load can be improved by the island operation mode in the event of a fault[1]. According to different types of DGs, the formation conditions of island are discussed in paper [2] and the calculation method of island formation probability is proposed. The influence of the operating strategy is proposed in paper [3].The paper [4] uses the reliability index to measure the reliability level of the AC power supply BSS.

When used as a power source, the influence of the BSS on the load reliability in the distribution network is not considered in the previous studies. When the BSS used as a power source, its function is similar to storing energy, it can be used with other DG together and function as part of the load power supply to improve the reliability of the distribution network in the event of a fault. Therefore, the calculation method of the island formation strategy is proposed in the paper and the island formation probability of DG and BSS is calculated, as well as the method of reliability evaluation of distribution network considering controllable DG, BSS and section switches.

1. PROBABILITY OF ISLAND FORMATION WITH DG AND BSS

The island operation mode is used in distribution network with DG to improve the system reliability. The charging and discharging characteristics of the energy storage station can be coordinated with the DG in the event of a fault in the distribution network to supply the islanding load and improve the reliability of the distribution network. If the sum of the output power of DG and BSS in the plan island can't meet the load demand, the island can't be formed. Therefore, formation of the island has a certain probability, and the probability will affect the reliability of the distribution network.

1.1 Reliability model of DG and BSS

The reliability model of DG uses the probabilities of its normal working condition and fault condition to describe. The probabilities of normal working condition and failure condition of DG are related with its failure rate and repair rate, and the equation is as follows:

$$\begin{cases} P_{1\mathrm{DG}} = \dfrac{\mu_{\mathrm{DG}}}{\lambda_{\mathrm{DG}} + \mu_{\mathrm{DG}}} \\ P_{0\mathrm{DG}} = \dfrac{\lambda_{\mathrm{DG}}}{\lambda_{\mathrm{DG}} + \mu_{\mathrm{DG}}} \end{cases} \tag{1}$$

where $P_{1\mathrm{DG}}$ and $P_{0\mathrm{DG}}$ are respectively the probabilities of the DG normal working condition and the fault condition; λ_{DG} and μ_{DG} respectively represent the DG failure rate and repair rate, which is the reciprocal of the repair time.

1.2 The Formation Probability of the Island with DG and BSS

The range of planned islands is obtained by the optimal allocation of the load and DG capacity.For an island with multiple DGs, any DG fault will make the island can't run stably, so the DG in the island is a series relation. Imagining that all the DGs in the island form a power block, the calculation equation of the power block reliability index is as follows:

$$\begin{cases} \lambda_{\mathrm{DG},i} = \sum_{j\in S_i} \lambda_{\mathrm{DG},j} \\ \gamma_{\mathrm{DG},i} = \dfrac{\sum_{j\in S_i} \lambda_{\mathrm{DG},j}\gamma_{\mathrm{DG},j}}{\lambda_{\mathrm{DG},i}} \\ \mu_{\mathrm{DG},i} = \dfrac{1}{\gamma_{\mathrm{DG},i}} \end{cases} \quad (2)$$

where $\lambda_{\mathrm{DG},i}$ and $\gamma_{\mathrm{DG},i}$ respectively represent the average failure rate and average repair time of the power block in the i-th island; $\mu_{\mathrm{DG},i}$ represents the repair rate of the power block in the i-th island, which is the reciprocal of the repair time; $\lambda_{\mathrm{DG},j}$ and $\gamma_{\mathrm{DG},j}$ respectively represent the failure rate and average repair time of the DG in the j-th island; S_i represents a set of DGs within the power block in the i-th island.

After determining the range of the planned island by DG capacity and maximum load value of distribution network, when DG in the island is in fault or short supply, if the maximum allowable discharge power of BSS is greater than the lack powerof DG, meanwhile the current charge of BSS allows it to discharge on the value which is greater than that DG short supply, under this circumstance, the BSS can coordinate with DG to form the island.

$$P_{\mathrm{bd},i} = \frac{\sum_{t\in T'} u_{\mathrm{bd},i}^{t}}{T'} \quad (3)$$

where $P_{\mathrm{bd},i}$ represents the probability that the maximum allowable discharge power of BSS in the i-th island is greater than the value that DG short supply; $u_{\mathrm{bd},i}^{t}$ represents the mark whether the maximum discharge power of BSS in the i-th island is greater than the value that DG short supply in time t , $u_{\mathrm{bd},i}^{t} = 1$ means the maximum discharge power of BSS in the i-th island is greater than the value that DG short supply, $u_{\mathrm{bd},i}^{t} = 0$ means the maximum discharge power of BSS in the i-th island is not greater than the value that DG short supply; T' represents the period when the DG is in short supply.

$$P_{\mathrm{be},i} = \frac{\sum_{t\in T'} u_{\mathrm{be},i}^{t}}{T'} \quad (4)$$

where $P_{\mathrm{be},i}$ represents the probability that the electrical power of BSS in the i-th island allows it to discharge on the value which is greater than that DG short supply in time t; $u_{\mathrm{be},i}^{t}$ represents the mark whether the electrical power of BSS in the i-th island allows it to discharge on the value which is greater than that DG short supply or not in time t; $u_{\mathrm{be},i}^{t} = 1$ means the electrical power of BSS in the i-th island allows it to discharge on the value which is greater than that DG short supply, $u_{\mathrm{be},i}^{t} = 0$ means the electrical power of BSS in the i-th island doesn't allow it to discharge on the value which is greater than that DG short supply.

If the DGs in the i-th island is in fault, the probability that the DGs is in normal work $P''_{\mathrm{1DG},i,s}$ and in fault $P''_{\mathrm{0DG},i,s}$ can be calculated by equation (1). In the i-th island, in addition to the DGs in fault, the other normal working DGs form a power block, the reliability index of it can be calculated by the equation (2), the probability that the power block is in normal work $P'_{\mathrm{1DG},i,s}$ and in fault $P'_{\mathrm{0DG},i,s}$ can be calculated by the equation (1).

Assume that the DG fault is a first order fault, for the island with controllable DG, distributed wind power and BSS,the island can be formed in the following 3 cases:

1) All DGs is in normal work and their output power can meet the load demand. In this case, the island formation probability $P_{\mathrm{on,a},i}$ is the same with the island with distributed wind power which is mentioned in the paper.
2) All DGs is in normal work but their output power can't meet the load demand, and BSS have the ability to make up for the short supply of the DG in the island. In this case, the island formation probability $P_{\mathrm{on,b},i}$ is as follows:

$$P_{\mathrm{on,b},i} = P_{\mathrm{1DG},i} * (1 - P_{\mathrm{m},i}) * P_{\mathrm{bd},i} * P_{\mathrm{be},i} \quad (5)$$

where $P_{\mathrm{1DG},i}$ is the probability that the power block in the i-th island is in normal work; $P_{\mathrm{m},i}$ is the probability that the output power of DG in the *i*-th island can meet the load demand.
3) Distributed wind power is in normal work, controllable DGs are in fault, and BSS have the ability to make up for the short supply of the DG in the island. In this case, the island formation probability $P_{\mathrm{on,c},i}$ is as follows:

$$P_{\mathrm{on,c},i} = \begin{cases} \sum_{s\in S_i} \left(P'_{\mathrm{1DG},i,s} * P''_{\mathrm{0DG},i,s} * P_{\mathrm{bd},i,s} * P_{\mathrm{be},i,s} \right) & ,|S_i|>1 \\ 0 & ,|S_i|=1 \end{cases} \quad (6)$$

where S_i represents a set of controllable DGs in the i-th island.
4) Controllable DG is in normal work, distributed wind power is in fault, and BSS have the ability to make up for the short supply of the DG in the island. In this case, the island formation probability $P_{\mathrm{on,d},i}$ is as follows:

$$P_{\text{on,d},i}=\sum_{s\in S_i}\left(P'_{1\text{DG},i,s}*P''_{0\text{DG},i,s}*P_{\text{bd},i,s}*P_{\text{be},i,s}\right) \quad (7)$$

where S_i represents a set of distributed wind power in the i-th island.

The probability of formation of the island with controllable DG, distributed wind power and BSS $P_{\text{on},i}$ is the sum of the four cases:

$$\begin{cases} P_{\text{on},i}=P_{\text{on,a},i}+P_{\text{on,b},i}+P_{\text{on,c},i}+P_{\text{on,d},i} \\ P_{\text{off},i}=1-P_{\text{on},i} \end{cases} \quad (8)$$

where $P_{\text{off},i}$ is the probability that the i-th island can't be formed.

The probability of formation of the island with only controllable DG and BSS $P_{\text{on},i}$ is:

$$\begin{cases} P_{\text{on},i}=P_{\text{on,a},i}+P_{\text{on,c},i} \\ P_{\text{off},i}=1-P_{\text{on},i} \end{cases} \quad (9)$$

2. RELIABILITY EVALUATION METHOD OF DISTRIBUTION NETWORK GIVEN CONSIDERATION TO CONTROLLABLE DISTRIBUTED GENERATION, BATTERY SWAPPING STATION AND SECTIONAL SWITCH.

First, using section algorithm of reliability evaluation for distribution network based on previous studies, distribution network is divided into network blocks; then, according to principle and method of island separation， the range of the island is determined. Afterwards, reliability indexes of every network blocks' load points inside and outside island are calculated. Finally, the system reliability indexes of the entire distribution network are obtained.

2.1 The calculation method of reliability indexes

If island can be formed， none of the loads will lose electricity power. If island cannot form, all of the load will lose electricity power. Therefore, reliability indexes of network blocks' equivalent load points are related to the formation probability of island:

$$\lambda_{j,i}=\lambda_j P_{\text{off},i} \quad (10)$$

where $\lambda_{j,i}$ is the failure rate of network block j of equivalent load points considering influence of DG and battery swapping station in the island i. λ_j is the failure rate of network block j of equivalent load points without considering influence of DG and battery swapping station in the island i.

(1)Index of energy not supplied

$$\text{ENS}=\sum_{k=1}^{N_K}\lambda_k\gamma_k P_k \quad (11)$$

where λ_k and γ_k are average fault rate and average fault repairing time of the kth network block's load points, respectively; P_k is the kth network block's load capacity; N_k is the number of network blocks in distribution network.

Index of power supply availability is:

$$\text{SAI}=\frac{8760-\sum_{k=1}^{N_K}\lambda_k\gamma_k}{8760}\times 100\% \quad (12)$$

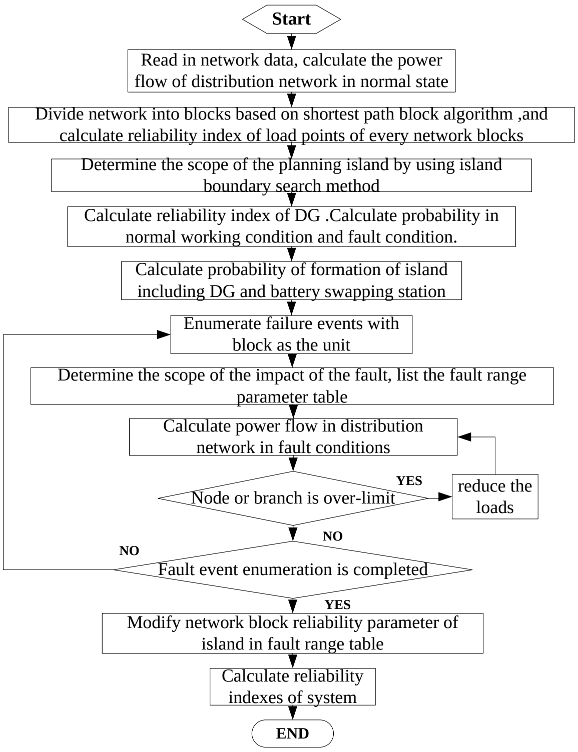

Figure 1 Reliability evaluation process of distribution network including controllable DG, BSS and section switch

2.2 The procedure of reliability evaluation of distribution network considering controllable distributed generation, battery swapping station and sectional switch

The flow chart of reliability evaluation considering controllable distributed generation, battery swapping station and sectional switch is as shown in Figure 1, and methods are as follow.

1) Input distribution networkdata. Analyze topology.
2) Divide distribution network into several network blocks.Calculate reliability index of load points of every network blocks.
3) Determine the scope of planning island.
4) Calculate thereliability parameters of power supply blocks in every islands by using equation(2).Calculate probability of network block's normal working and fault condition as well as formation probability of island not including battery swapping station by using equation(1).Calculate

probability of formation of island including battery swapping station by using equation (8) and equation(9).

5) Enumerate fault events in network blocks.
6) Identify breakdown influence scope without considering influence of DG and BSS, and list a table to record network blocks number in breakdown influence scope and reliability index of load points of network blocks.
7) Calculate power flow in distribution network when a fault occurs, and find out whether some node voltages or capacity are out -of -limit or not. If so, reduce the loads.
8) Check if all fault events are enumerated or not. If not, go to the fifth step.
9) Correct reliability index of load points of network blocks in island within the breakdown influence scope table by using equation (10).
10) Calculate system reliability index considering influence of DG and BSS by using equation (10) and equation (11),output the result.

3. ANALYSIS OF THE EXAMPLE

3.1. The basic data of the example and simulation condition

The data of the IEEE three feeder systems are shown in document, and the placement of sectional switches is shown in Figure 2. The boxes are sectional switches and '×'is circuit breakers in this figure. Without considering fault switch and time of switch action, the failure rate of line, controllable DG and distributed wind power in distribution network are 0.05 times per year, 0.5 times per year and 1 times per year respectively. Fault repairing time is 4 hours each time,12 hours each time and 60 hours each time respectively. And analyze the following four cases.

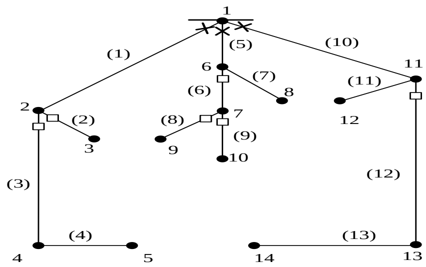

Figure 2 placement of sectional switches of IEEE three feeders system

Scheme 1: Not configure DG and BBS.
Scheme 2: Access distributed wind powers whose unit capacity is 5MW,10MW and 3MW on node 5,10 and 14. Cut-in, cut-out and rated wind speed is 3.5m/s,20m/s and 12m/s respectively. Install controllable DG whose unit capacity is 0.3MW, 0.2MW, 0.4MW, 1.1MW and 0.5MW on Node 4,5, 7 and 14, respectively.
Scheme 3: On the basis of mode 2, install BBS whose number of battery is 100,113,135 and number of charging and discharging devices is 86, 102, 111, respectively.
Scheme 4: On the basis of mode 2, install BBS whose number of battery is 226,220,270 and number of charging and discharging devices is 204, 172 and 222, respectively.

3.2 Results and analysis of the example

Under the four schemes, average fault rate of load points and annual average interruption time are shown in Figure 3 and Figure 4, respectively. Index oflack power in the systemand power supply availability every year listed in Table 1.

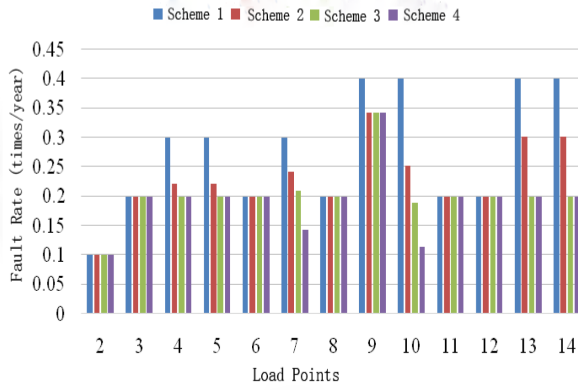

Figure 3 Comparison of fault rate index of load points under four schemes

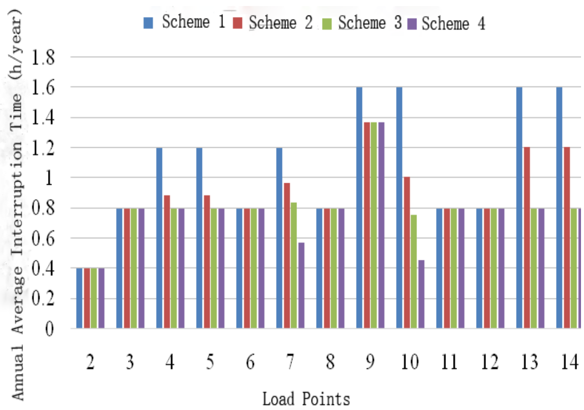

Figure 4 comparison of annual average interruption time of load points under four schemes

Table 1 Index of energy not supplied of system and power supply availability every year

Index of system reliability	Scheme1	Scheme2	Scheme3	Scheme4
ENS（MWh）	32.12	25.82	22.49	19.81
SAI	99.89%	99.91%	99.92%	99.92%

Three islands are formed under the Scheme 2. Load points are 4 and 5 in the island 1.Load points are 7, 9 and 10 in the island 2 and load points are 13 and 14 in the island 3. It can be seen that index of reliability of partial load points decrease obviously in the island, but index of reliability of load points remains unchanged outside the island after DG connected to the distribution network. The results show that the installation of DG improves the reliability of load points in island.

In Scheme 3, the BSS is connected based on Scheme 2.Comparing the index of reliability of load points in the island, it can be seen that the installation of BBS further decrease the index of reliability of partial load points and improves the reliability of load in island.

Compared to Scheme 3, capacity of BBS increase in the Scheme 4 .Comparing the index of reliability of load points, it can be seen that the index of reliability of partial load points in the island are low when the capacity of BSS are large.

The results show that configuration of capacity of BSS do have influence on the reliability of load in the island.Therefore, when DG and BSS are connected to the distribution network, islanding can ensure the reliability of load in the island to improve reliability of the distribution network.Therefore, evaluation of reliability in distribution network including controllable distributed generation, BSS and sectional switch is of great importance for distribution network planning.

4. CONCLUSION

The calculation method of island formation strategy is presented in this paper and island formation probability including DG and BSS is calculated to analyse the reliability evaluation in distribution network considering controllable DG, BSS and sectional switch. By constructing four different configuration plans in the three feeder system, four kinds of schemes are evaluated. The validity and correctness of the method of reliability evaluation including DG and BSS presented in this paper are verified. The result shows that islanding can ensure the reliability of load in the island to improve reliability of the distribution network when DG and BSS are connected to the distribution network.

REFERENCES

[1] Bae, In-Su,Kim, Jin-O.Reliability evaluation of distributed generation based on operation mode. IEEE Transactions on Power Systems. 2007

[2] Zheng Y, Dong Z Y, Xu Y, et al. Electric Vehicle Battery Charging/Swap Stations in Distribution Systems: Comparison Study and Optimal Planning[J]. IEEE Transactions on Power Systems. 2014, 29(1): 221-229.

[3] Bhuiyan, F.A.,Yazdani, A.Reliability assessment of a wind-power system with integrated energy storage. Renewable Power Generation, IET . 2010

[4] Yu Rongrong. Study on Key Technologies of Photovoltaic Power Generation System and Reliability of Electric Vehicle Charging Station[D]. Beijing Jiaotong University, 2011. (in Chinese)