Reliability analysis of microgrid based on load control of electric vehicle

Jiachao Chen¹, Xu Chen², Linhao Ye², Tingcheng Huang³ and Yongjun Zhang¹

1 School of Electric Power, South China University of Technology, Guangzhou, Guangdong, China
2 China Southern Power Grid Company Limited, Guangzhou, Guangdong, China
3 Guangzhou Power Electrical Technology Co. Ltd., Guangzhou, Guangdong, China
E-mail: 1298554802@qq.com

Abstract. With the development of renewable energy technologies, microgrid with distributed energy as the main energy source develops rapidly. As a kind of controllable load, electric vehicles can make up for the impact on the microgrid when they are connected to the microgrid in large quantities, so as to avoid load cutting due to insufficient power generation. In this paper, the reliability of microgrid island operation with wind power generation is studied based on the control strategy of electric vehicle. Firstly, the minimum peak load model of electric vehicles is established to evaluate the regulatory potential of electric vehicles during the island operation of microgrid. Secondly, the source-load-storage joint control strategy of microgrid with power supply reliability is proposed. Then, based on Monte Carlo simulation, a microgrid reliability assessment method based on the minimum peak load model of electric vehicles is proposed. Finally, a numerical simulation is carried out through the modified RBTS Bus6 F4 feeder system. Simulation results verify the effectiveness of the proposed model and strategy.

1. Introduction
Grid-connected microgrid can disconnect from the external power grid when the external power grid fails or there is power quality problem, enter the island operation mode, and be jointly supplied by the internal distributed generation (DG) and energy storage of the microgrid, so as to improve the power supply reliability and power quality [1]. In order to ensure reliable power consumption of island operation load, the microgrid needs to be equipped with sufficient capacity of DG and energy storage. In the current situation of high energy storage cost, it is an effective measure to improve the reliability and economy of microgrid to reduce the DG and energy storage capacity of microgrid by reasonable regulation of demand-side [2].

Electric vehicle (EV), with long idle time and flexible spatiotemporal characteristics of charging [3], is one of the demand side resources with strong controllability in microgrid. When the number of EVs reaches a certain scale, the EVs in a region can be aggregated to participate in the regulation of the grid through the economic incentives of load aggregator (LA) [4]. For example, the literature [5] uses the mobile energy storage characteristics of EV to regulate the EV to stabilize the bus voltage fluctuation of the DC microgrid. Literature [6] realizes the improvement of the overall economy and environmental benefits of microgrid through the coordinated control of EV and renewable energy power generation. Literature [7] regulates EV’s participation in power system frequency regulation.

Power supply reliability, as an important operational indicator of the power grid, can reflect the number of power outages, time and lost load of the power grid and users. EV mainly affects the reliability of distribution network by increasing power load demand, changing load space-time...
distribution and other ways [8]. In [9], EV is equivalent to standby power supply, and the reliability evaluation algorithm of distribution network in V2G mode is proposed to improve the reliability level of the distribution network; Literature [10] combines EV with DG, and literature [11] combines EV, DG and energy storage to form a joint power generation system for quantitative evaluation of EV distribution network reliability. In general, most of the current relevant studies only consider EV as a power source for mobile energy storage in the reliability evaluation of distribution network. However, reasonable regulation of load by means of electricity price or economic incentive can effectively improve the reliability of power supply [12,13]. But there is no research on EV load regulation potential and regulation strategy in the reliability evaluation of microgrid. Therefore, this paper focuses on the microgrid reliability evaluation, which takes into account EV load control potential and strategies. The EV regulatory potential of the microgrid in the island operation period was evaluated by establishing the minimum peak load model of EV, and then the EV (controllable load) and energy storage in the microgrid in the island operation period were jointly regulated. Then the reliability of micro grid is evaluated and the simulation results verify the effectiveness of the proposed model and strategy. On the basis of meeting EV charging requirements and regulating EV and energy storage according to the proposed joint regulation strategy of micro grid, the influence of large-scale EV access on the reliability of micro grid can be effectively reduced and the reliability of micro grid can be improved.

2. Minimum peak load model for EV

In the isolated island operation, the microgrid load is completely powered by DG and energy storage. As EV charging time is flexible, EV charging load can be cut out first when its charging demand is met. At the same time, since the microgrid needs to wait for the fault repair or power transfer of external power grid to resume the grid-connected operation, EV load regulation potential during the entire island operation period needs to be evaluated.

To this end, this chapter establishes the minimum peak load model of electric vehicles to evaluate the minimum EV peak load that can be achieved after regulation on the basis of meeting EV charging requirements during the operation period of the isolated island, as shown in the following formula:

$$\min f = \max (AP)$$

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1(N-1)} & a_{1N} \\ a_{21} & a_{22} & \cdots & a_{2(N-1)} & a_{2N} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ a_{(J-1)1} & a_{(J-1)2} & \cdots & a_{(J-1)(N-1)} & a_{(J-1)N} \\ a_{J1} & a_{J2} & \cdots & a_{J(N-1)} & a_{JN} \end{bmatrix}$$

$$P = \begin{bmatrix} P_{1}^{EF} \\ P_{2}^{EF} \\ \vdots \\ P_{N}^{EF} \end{bmatrix}$$

Where, $A$ is EV charging state matrix; $N$ is the number of EV; $J = T_{k} / \Delta t$, $T_{k}$ is the operation time of the isolated island of microgrid, that is, the regulation time of EV, and $\Delta t$ is the regulation time interval; $a_{ij}$ is the 0-1 variable that represents the charging state of the $j$th EV during the period $t_{i}$. 1 represents the charging state and 0 represents the non-charging state. $P$ is the EV charging power matrix, and $P_{j}^{EF}$ is the charging power of the $j$th EV.

At the same time, the regulation of EV by LA should meet the charging requirements of the car owner. In the regulation of EV, EV charging plan information should be obtained, including: current battery charging state $S_{SOC}^{1}$ (state of charge (SOC)), current time $t^{1}$, expected departure time $t^{2}$, expected charging state $S_{SOC}^{2}$ at departure, battery capacity $B$, charging power $P_{j}^{EV}$. According to the charging plan information, EV charging demand constraints can be obtained as follows:

(1) electric vehicle charging capacity constraint
During EV regulation period, the charging amount of EV should not be less than its minimum charging amount in the regulation period, and the electric quantity after charging should not be greater than its capacity upper limit.

\[
(S^{oc3}_j - S^{oc1}_j)B \leq \sum_{i=1}^{I} a_{ij} \Delta t_{ij}^{EV} \leq (S^{max}_j - S^{oc1}_j)B
\]

(4)

Where: \( S^{oc1}_j \) represents the SOC state of the jth EV at the beginning of regulation; \( S^{max}_j \) represents the SOC upper limit of jth EV to avoid EV overcharging; \( S^{oc3}_j \) represents the SOC state that the jth EV needs to reach at least in the regulation period. \( S^{oc3}_j \) depends on the estimated departure time \( T^2_j \) of the EV. If EV leaves during the island operation period, \( S^{oc3}_j = S^{oc2}_j \). If EV leaves after the operation of the island, \( S^{oc3}_j \) is equal to the difference between \( S^{oc2}_j \) and EV’s charging capacity after the operation of the island, as shown in the following formula.

\[
S^{oc3}_j = \left\{ \begin{array}{ll}
S^{oc2}_j & \text{if } T^2_j \leq T_k \\
S^{oc2}_j - \frac{(T^2_j - T_k) P^{EV}_j}{B} & \text{if } T^2_j > T_k
\end{array} \right.
\]

(5)

(2) charging time constraint of electric vehicles
After EV leaves the grid, its charging state variable \( a_{ij} \) is 0.

\[
\text{if } i \geq T^2_j, \quad a_{ij} = 0
\]

(6)

The above model can be solved by GAMS optimization software, and the minimum EV peak load value \( P^{min}_i \) in the period of isolated island can be obtained by solving the model, which can serve as the load cutting criterion during the island operation period.

3. Microgrid regulation strategy considering power supply reliability
In the operation process of microgrid, DG output, load, EV quantity connected to the grid and charging power all change with time. The above minimum peak load model solution results do not take into account the changes in subsequent periods, and cannot be used for EV charging control in the operation process of microgrid island. Therefore, this chapter considers the time-varying of DG, load and EV, and proposes a joint regulation strategy for EV and energy storage that takes into account the reliability of the microgrid.

Assuming that the time when the microgrid enters the island operation is \( t_0 \), for the ith regulation period \( \Delta T_i = [t_i, t_0 + i \Delta t] \), where \( t_i = t_0 + (i-1) \Delta t \), the minimum peak load value \( P^{min}_i \) of EV in the \( [t_i, t_0 + T_k] \) period is first solved according to the minimum peak load model.

(1) if DG output power \( P^{DG}(t_i) \) is less than the sum of conventional load \( P^{L}(t_i) \) and \( P^{min}_i \), that is, \( P^{DG}(t_i) < P^{L}(t_i) + P^{min}_i \). Energy storage requires discharge to maintain power balance.

A. If the maximum discharge power \( P^{ESS}_{max} \) of the energy storage is insufficient to supply the load, that is, \( P^{DG}(t_i) < P^{L}(t_i) + P^{min}_i \), or the energy storage available capacity \( Q_{ESS}(t_i) \) is insufficient to maintain the power supply demand of the \( \Delta T_i \) period, that is, \( Q_{ESS}(t_i) < [P^{L}(t_i) + P^{min}_i - P^{DG}(t_i)] \Delta t \), part of the load needs to be cut according to the power shortage.

B. If \( P^{ESS} \geq P^{L}(t_i) + P^{min}_i - P^{DG}(t_i) \) and \( Q_{ESS}(t_i) \geq [P^{L}(t_i) + P^{min}_i - P^{DG}(t_i)] \Delta t \), EV charging power is \( P^{min}_i \) during \( \Delta T_i \) period, and energy discharge of power storage is
\[ P_{\text{ESS}}(t_i) = P^{DG}(t_i) - P^L(t_i) - P_{\text{min},i} \]  

(7)

(2) if \( P^{DG}(t_i) \) is greater than the sum of \( P^L(t_i) \) and \( P_{\text{min},i} \), that is, the output of DG can meet the load demand and EV basic charging demand. At this time, the surplus power of DG should be distributed according to the energy storage state.

The distribution method of DG surplus power is as follows:

The maximum average output power \( P_{\text{max}}^{\text{ESS}} \) of the energy storage device during the microgrid island operation is

\[ P_{\text{max}}^{\text{ESS}} = \min\left\{ \frac{Q(t_0) - Q_{\text{min}}}{T_K}, P_{\text{max}}^{\text{ESS}} \right\} \]  

(8)

Where: \( Q(t_0) \) is the energy storage quantity at the beginning of the island in the microgrid; \( Q_{\text{min}} \) is the minimum capacity limit of energy storage.

![Energy storage capacity curve.](image)

As shown in figure 1, the solid red line \( l \) indicates that the energy storage is continuously discharged with the power \( P_{\text{max}}^{\text{ESS}} \) during the regulation period until the end of the microgrid island operation, and the solid blue line indicates the capacity state that the energy storage may actually appear.

C. If the average output power of energy storage during \( t_0 \sim t_i \) is less than \( P_{\text{max}}^{\text{ESS}} \), the state point of energy storage power at \( t_i \) time is above \( l \), as shown in figure 1, point A, indicating that the actual energy storage power is greater than the expected residual power. At this time, the surplus power of DG is given priority to EV charging. The condition for judging the state of energy storage and electric quantity is:

\[ Q(t_i) > Q(t_0) - (i-1)\Delta t P_{\text{max}}^{\text{ESS}} \]  

(9)

EV charging power \( P^{\text{EV}}(t_i) \) is

\[ P^{\text{EV}}(t_i) = \min\{P^{DG}(t_i) - P^L(t_i), P_{\text{max}}^{\text{EV}}(t_i)\} \]  

(10)

Where, \( P_{\text{max}}^{\text{EV}}(t_i) \) is the maximum charging power of EV at time \( t_i \). Due to the different charging plans of different EV, EV load will have different influences on the following period of time. Specific EV charging arrangements cannot be obtained only according to the total EV charging power \( P^{\text{EV}}(t_i) \). Therefore, the minimum peak load model of EV was improved in this paper to obtain EV charging arrangement in period \( \Delta T_i \). Add constraint conditions on the basis of EV minimum peak load model established in the previous section:
\[
\sum_{j=1}^{N} a_j P_j^{\text{EV}} \leq P^{\text{EV}}(t_i)
\]  

(11)

Solve the EV minimum peak load model in time period \([t_{i+1}, t_0 + T_K]\), and then obtain EV charging arrangement in time period \(\Delta T\) that could minimize EV load peak in the remaining time period.

The actual charging power of energy storage is between the slope of the dotted line \(l_1\) and \(l_2\), and its calculation formula is as follows:

\[
P^{\text{ESS}}(t_i) = \max[P^{\text{DG}}(t_i) - P^c(t_i) - \sum_{j=1}^{N} a_j P_j^{\text{EV}}, 0]
\]

(12)

If there is still a surplus after the DG power is allocated to the normal load and the EV, the surplus power is allocated to the energy storage, otherwise the energy storage power is zero.

D. If the average output power of energy storage is greater than \(P_{\text{ESS}}^{\text{max}}\) during \(t_0\) to \(t_i\), the state point of energy storage power at \(t_i\) is located below \(l\), as shown in figure 1, point B, indicating that the actual energy storage power is less than the expected residual power. At this time, the surplus power of DG is given priority to energy storage charging. The energy storage and charging power is between the slope of the dotted line \(l_3\) and \(l_4\), i.e. \([0, P_{\text{ESS}}^{\text{max}}]\). The calculation formula is:

\[
P^{\text{ESS}}(t_i) = \min[P^{\text{DG}}(t_i) - P^c(t_i) - P_{\text{ESS}}^{\text{min}}, P_{\text{ESS}}^{\text{max}}]
\]

(13)

Similarly, add constraints to the EV minimum peak load model:

\[
\sum_{j=1}^{N} a_j P_j^{\text{EV}} \leq P^{\text{DG}}(t_i) - P^c(t_i) - P^{\text{ESS}}(t_i)
\]

(14)

Solve the EV minimum peak load model in time period \([t_{i+1}, t_0 + T_K]\), and then obtain the EV charging arrangement in time period that could minimize the EV load peak in the remaining time period.

4. Reliability Assessment of Microgrid Considering Control Strategy

Reasonable regulation of EV, DG and energy storage can reduce the adverse impact of large-scale EV access and even improve the reliability level of microgrid. Therefore, based on Monte Carlo simulation method, this section studies the reliability evaluation method of microgrid considering the proposed regulation strategy. The evaluation steps are as follows:

1) Initialize microgrid data and set simulation times;

2) Randomly sample the trouble-free operating time of all components of the microgrid based on component failure rate.

3) Analyse the failure consequences of all components with time between failures less than 8760 hours. According to the electrical position of the fault element, the load is divided into five categories: class A is the load that is not affected by the fault of the element, and class B is the load that can be restored to power supply after fault isolation; Class C is a load that can be restored by switching to another power supply; Class D is non-convertible load.

4) No power failure for class A load; B, C and D have one power failure each. The power failure time is the fault isolation time, the load resupply time and the repair time of the fault components, respectively. The power failure time, power failure times and loss load of each load are accumulated respectively.

5) According to the islanding operation rate of microgrid, random sampling is made for the operation time of interconnection of microgrid and islanding operation time. If the island operation of microgrid fails, the power failure time, power failure times and loss load of each load will be accumulated. If the island operation of microgrid is successful, the control can be carried out according to the microgrid regulation strategy proposed in this paper. The flow chart is shown in
In the process of island operation of microgrid, if the load is cut off, the power failure time, power failure times and loss load of the cut load will be accumulated.

6) Determine whether the current simulation time reaches the set number of simulation times; if not, return to step 2); if yes, perform the next step.

7) Add the power failure frequency, power failure time and loss load of each load point, calculate the reliability index of the load point, and finally calculate the reliability index of the microgrid. The method includes the system average interruption frequency index (SAIFI), the system average interruption duration index (SAIDI) and the reliability index of the average service availability index (ASAI) and expected energy not supplied (EENS).

\begin{align*}
Y & \text{Start} \\
\text{P}^{\text{min}}(t) & < \text{P}(t) + P_{\text{min}}^c \\
\text{Q}(t) & < \text{Q}((t-(i-1))t) + P_{\text{min}}^c \\
\text{P}^{\text{min}}(t) & = \text{min}[\text{P}^c(t)-\text{P}(t)-P_{\text{min}}^c] \\
\sum a_i P^c & \leq \text{P}^c(t) - \text{P}(t) - P_{\text{min}}^c \\
\text{P}^{\text{max}}(t) & = \max[\text{P}^c(t)-\text{P}(t)-\sum a_i P^c, 0] \\
\text{dd constraints} & \\
\text{The EV minimum peak load} & \\
\text{solved to obtain EV char} & \\
\text{arrangement in this per} & \\
\text{P}^{\text{min}}(t) & = \text{P}^c(t) + P_{\text{min}}^c - \text{P}(t) + P_{\text{min}}^c \\
\text{P}^{\text{max}}(t) & = \text{P}^c(t) - \text{P}(t) - P_{\text{min}}^c \\
\text{P}^c(t) & = \text{min}[\text{P}^c(t) - \text{P}(t) - P_{\text{min}}^c] \\
\sum a_i P^c & \leq \text{P}^c(t) - \text{P}(t) - P_{\text{min}}^c \\
\text{P}^{\text{max}}(t) & = \max[\text{P}^c(t) - \text{P}(t) - P_{\text{min}}^c, 0] \\
\text{dd constraints} & \\
\text{The EV minimum peak load} & \\
\text{solved to obtain EV char} & \\
\text{arrangement in this per} & \\
\text{P}^{\text{min}}(t) & = \text{P}^c(t) + P_{\text{min}}^c - \text{P}(t) + P_{\text{min}}^c \\
\text{P}^{\text{max}}(t) & = \text{P}^c(t) - \text{P}(t) - P_{\text{min}}^c \\
\text{P}^c(t) & = \text{min}[\text{P}^c(t) - \text{P}(t) - P_{\text{min}}^c] \\
\sum a_i P^c & \leq \text{P}^c(t) - \text{P}(t) - P_{\text{min}}^c \\
\text{P}^{\text{max}}(t) & = \max[\text{P}^c(t) - \text{P}(t) - P_{\text{min}}^c, 0] \\
\text{dd constraints} & \\
\text{The EV minimum peak load} & \\
\text{solved to obtain EV char} & \\
\text{arrangement in this per} &
\end{align*}

**Figure 2.** Microgrid regulation process considering power supply reliability.

5. Case analysis

5.1. Illustration of calculation example

Part of the load of the F4 main feeder of the improved rbts-bus6 system is combined with DG and energy storage to form the microgrid, as shown in figure 3.
Connect GT of micro gas turbine set at feeder 1, the maximum power of which is 0.6MW; Energy storage system ST, capacity 2MW·h, maximum power 1MW; Wind turbine WT, the maximum power of which is 1.5mw, and the wind speed of cut in, rated and cut out are respectively 9,38,80km/h. Assuming that the wind speed obeys the Weibull distribution with two parameters, and its shape parameter k is 2 and scale parameter c is 8.03.

S1, S2 and S3 are intelligent quick break switches. The smart switch is used as the cut-off point to divide the microgrid into A, B and C load blocks. The length of the circuit and the reliability parameters of the circuit and transformer and other components are detailed in the literature [14]. Load parameters are detailed in literature [15].

LP3 was selected as the load point for EV access. According to the current situation and development prospect of EV, EV parameters in the calculation example were set as follows:

1) 300 EV are connected to LP3;
2) EV battery capacity is 40kW·h;
3) EV adopts a constant power charging model with a power of 8kW;
4) assume that the EV is uniformly distributed within 24 hours when it is connected to the power grid, and the SOC state of the battery is uniformly distributed [0.2,0.8] when it is connected to the power grid;
5) EV residence time obeys the uniform distribution of 4-8h, and the expected battery SOC when EV leaves is 1.

5.2. Analysis of simulation results

In this paper, the following two regulatory strategies are set up for reliability evaluation and comparative analysis of micro grid.

Strategy 1: no EV regulation;
Strategy 2: the microgrid regulation strategy based on EV minimum peak load model is proposed in this paper.

Element in Matlab software programming using the Monte Carlo simulation method of random sampling running state, the electric car charging information, at the same time in the simulation of strategy 2 calls GAMS software to solve the model, the peak load of EV minimum and will return to the model result of Matlab for EV regulation and energy storage, and finally the reliability assessment, and through multiple simulation averaging method to reduce the error caused by random sampling.

The evaluation results of microgrid reliability under different strategies are shown in table 1.

| Microgrid reliability index | Strategy 1 | strategy 2 |
|-----------------------------|------------|------------|
| SAIFI/(Times·a⁻¹)           | 1.571      | 1.394      |
| SAIDI/(h·a⁻¹)               | 8.916      | 7.875      |
| ASAI/%                      | 99.90      | 99.91      |
| EENS/(MW·h)                 | 40.32      | 34.75      |

As can be seen from table 1, compared with strategy 1, all the power supply reliability indexes of the microgrid under strategy 2 have been effectively improved. The average annual power failure frequency of the microgrid load has decreased by 11.27%, the average annual power failure time has decreased by 11.68%, and the average annual shortage load has decreased by 13.8%.

The simulation results show that the control strategy of microgrid based on EV minimum peak load model proposed in this paper can reasonably regulate the charging load of EV on the basis of meeting the charging demand of EV, reduce the number and load shedding of microgrid, reduce the outage time and number of users, reduce the impact of large-scale EV access on Grid reliability, and improve the reliability of microgrid.

6. Conclusion

In view of the flexible charging time and good regulatory performance of EV, they can be used as a controllable load to participate in the load regulation of the microgrid island operation to avoid load
cutting because the DG power generation is less than the load, this paper established the EV minimum peak load model to evaluate the EV regulatory potential during the microgrid island operation period. An EV-energy storage joint control strategy for microgrid considering power supply reliability is proposed. The operation status of EV and energy storage is regulated according to the real-time load, power generation, energy storage status and EV regulation potential of microgrid in isolated islands. Then, Monte Carlo simulation method is used to evaluate the reliability of microgrid based on the minimum peak load model of EV. Finally, an improved RBTS Bus6 F4 feeder system is used for simulation. Simulation results verify the effectiveness of the proposed model and strategy. On the basis of meeting EV charging requirements, joint regulation of EV charging load and energy storage can effectively reduce the impact of EV access on reliability and improve the reliability level of microgrid. In general, the proposed joint regulation strategy is a feasible measure to improve the reliability and economy of EV access microgrid.

At the same time, the research in this paper only takes EV as a controllable load and does not consider its impact on the reliability of microgrid when it is used as mobile energy storage. This should be considered in the next research to further improve the reliability level of microgrid.

7. References
[1] Li Y W, Miao S H, Liu J Y et al. 2018 Optimal allocation of energy storage system in PV micro grid considering uncertainty of demand response Power System Protection and Control 46 69-77
[2] Gao C W, Li Q Y and Li Y. 2014 Bi-level Optimal Dispatch and Control Strategy for Air-conditioning Load Based on Direct Load Control Proceedings of the CSEE 34 1546-1555
[3] Liu H, Huang K, Yang Y et al. 2018 Real-time vehicle-to-grid control for frequency regulation with high frequency regulating signal Protection and Control of Modern Power Systems 3 13
[4] Li B S, Wang X, Jiang C W, et al. 2018 Market strategy modeling and risk profit analysis of demand-side resource aggregator Automation of Electric Power System 42 119-126+236-239
[5] Wang S S, Zhao J B, Mao L et al. 2018 A control strategy based on mobile energy storage characteristic of electric vehicles in DC micro-grid Power System Protection and Control 46 31-38
[6] Hu K W, Liaw C M. 2016 Incorporated operation control of DC microgrid and electric vehicle IEEE Transactions on Industrial Electronics 63 202-215
[7] Bao Y, Jia L M, Jiang J C et al. 2015 Research on the control strategy of electric vehicle mobile energy storage in ancillary frequency regulation Transactions of China Electrotechnical Society 30 115-126
[8] Guo J L, Wen F S. 2015 Impact of electric vehicle on power system and relevant countermeasures Electric Power Automation Equipment 35 1-9+30
[9] Wang X, Yang J W, He Z Y. 2014 A reliability evaluation algorithm for distribution network under V2G mode considering probabilities of breaking and load transfer Power System Technology 38 2213-2219
[10] Yin Z L, Zheng P X, Chen Y X et al. 2017 Reliability evaluation for distribution network with electric vehicle and distributed generation. Power System Protection and Control 45 77-83
[11] Bai H, Miao S H, Qian T T et al. 2015 Reliability assessment based on combined power generation system for distribution system with electric vehicle Transactions of China Electrotechnical Society 30 127-137
[12] Zhou B R, Huang T C and Zhang Y J. 2017 Reliability evaluation of microgrid considering incentive demand response Automation of Electric Power Systems 41 70-78
[13] Zhao H S, Wang Y Y, Chen S. 2015 Impact of demand response on distribution system reliability Automation of Electric Power Systems 39 49-55
[14] ALLAN R N, BILLINTON R, SIARIEF I et al. 1991 A reliability test system for educational purposes-basic distribution system data and results IEEE Trans on Power Systems 6 813-820
[15] BILLINTON R, JONNAVITHULA S. 1996 A test system for teaching overall power system reliability assessment IEEE Trans on Power Systems 11 1670-1676