Component Importance Assessment for Improving Power System Resilience

Xiaohai Gao
Economic&Technology Research Institute
State Grid ShanDong Electric Power Company
Jinan, China
xiaohaigao@163.com

Xiaoming Liu
Economic&Technology Research Institute
State Grid ShanDong Electric Power Company
Jinan, China
xiaomingliu@163.com

Long Zhao
Economic&Technology Research Institute
State Grid ShanDong Electric Power Company
Jinan, China
longzhao@163.com

Hailan Zeng
School of Electrical Engineering
Xi'an Jiaotong University
Xi'an, China
charles_fin_leo@stu.xjtu.edu.cn

Hao Zhu
School of Electrical Engineering
Xi'an Jiaotong University
Xi'an, China
dreamerzh@stu.xjtu.edu.cn

***Abstract*—With global climate change, the frequency of natural disasters is gradually increasing. In order to reduce the loss caused by natural disasters, it is necessary to improve the resilience of the power system. The component assessment is crucial for the resilience enhancement. This paper proposes a component importance assessment method for the distribution system under wind storms. Based on a component failure model under wind storms, the non-sequential Monte Carlo simulation method is used to sample different system states. For each system state, the post-disaster restoration process is formulated as a mixed integer linear programming model, which considers the scheduling of the repair crew and the mobile power source. Copeland ranking method is utilized to rank the component importance. Finally, this paper implements the proposed assessment method on the IEEE-33 node distribution test system to verify the validity of the method.**

Keywords—distribution system, component importance assessment, resilience, Copeland ranking method, repair crew scheduling, mobile power source

I. Introduction

In recent years, the frequency of low probability and high impact events such as the typhoon have gradually increased[1]. In 2012, Hurricane Sandy caused a "N-90" failure and resulted in power outage to 7.5 million users in 15 states of the United States. In 2019, super typhoon Lekima attacked eastern China and caused power outage to 2.87 million households. These natural disasters caused huge economic losses to the power system and hindered social development.

To address natural disasters, resilience is introduced into the power system. Many research works have been carried out around the power system resilience enhancement. The enhancement method includes pre-disaster component reinforcement and post-disaster fast restoration. The component importance has a significant impact on both methods. In [2], Zhao et.al introduced the concept of core skeleton network (CSN) , and utilized a statistical salience method integrated with edge salience of complex network theory to identify the important line of the CSN. In [3], Espinoza et.al built a component vulnerability model under earthquake and used Monte Carlo simulation to sample the scenarios. Fussell–Vesely (FV) importance measure was utilized to compare the risk of default network and the risk considering component failure. The component importance was assessed through the contribution of component failure to system risk. In [4], Fu et.al proposed a component importance assessment method in the context of interdependence between transmission, distribution and communication networks. Based on physical characteristics of three systems, analytic methods were applied for assessing the component importance. In [5], authors considered the system risk and the e proposed a novel coalitional insurance design for integrated power and natural gas systems against extreme weather. Considering the component repair, Li et.al proposed a component importance assessment approach for power systems based on Copeland ranking method in [6]. Copeland ranking method can give the component importance score through the comparison between selected indices, which doesn't require much information or data. The work in [6] is mainly aimed at the transmission grid. Different from the transmission grid, the distribution system is equipped with many flexible resources, such as distributed generators(DGs) and mobile power sources(MPSs). These flexible resources will cooperate with the repair crew during the post-disaster restoration, which may change the sequence of component repair. It is meaningful to consider the impact of flexible resources in component importance assessment. However, the effect of flexible resources was ignored in the previous work.

To fill the research gap, this paper proposes a component importance assessment method for the distribution system containing DGs and MPSs in the wind storm. Firstly, a component failure model under wind storms is established to obtain the component failure probability. Based on the component failure probability, the non-sequential Monte Carlo simulation method is used to sample system states. Then a post-disaster restoration model considering the scheduling of repair crews, DGs and MPSs is proposed to calculate the optimal repair sequence. Finally, Copeland ranking method is used to score the component importance according to the repair sequence.

This paper is organized as follows: Section II presents the mathematics formation of the component failure model and the poste-disaster restoration model. Section III shows the whole process of component importance assessment. Section IV presents the result of the case study. Conclusions are drawn in Section V.

This work was supported by State Grid Shandong Electric Power Company Sci & Tech Project (5206002000U7).

2023 International Conference on Power System Technology (PowerCon) | 979-8-3503-0022-2/23/$31.00 ©2023 IEEE | DOI: 10.1109/POWERCON58120.2023.10331608

979-8-3503-0022-2/23/$31.00 ©2023 IEEE

II. Mathematics Formation

A. Component Failure Probability Model Under Wind Storm

The component failure probability is mainly related to the wind speed. The relationship between the component failure rate and the wind speed can be obtained through the exponential fitting method[7]:

$$\lambda_{\text{wind}}\left(\omega(t)\right)=\left(\gamma_1 e^{\gamma_2\omega(t)}-\gamma_3\right)\lambda_{\text{norm}} \tag{1}$$

where λ_{wind} is the failure rate of each component. $\omega(t)$ is the wind speed at the time t. λ_{norm} is the normal failure rate of the component under normal weather. γ_1, γ_2, γ_3 are fitting coefficient, which are described as follows:

$$\lambda_{\text{wind}}\left(\omega_{\text{crit}}\right)=\left(\gamma_1 e^{\gamma_2\omega_{\text{crit}}}-\gamma_3\right)\lambda_{\text{norm}}=\lambda_{\text{norm}} \tag{2}$$

where ω_{crit} is the critical wind speed where λ_{wind} starts to increase.

The relationship between failure rate and failure probability [8] can be expressed as:

$$q_{\text{wind}}=1-e^{-\lambda_{\text{wind}}T} \tag{3}$$

where q_{wind} is the failure probability, T is the related time of failure rate.

B. Poste-disaster Restoration model

Considering the scheduling of repair crews, DGs and MPSs, the post-disaster restoration is formulated as a mixed integer linear programming(MILP) model.

1) Objective function

$$\min\sum_{t\in T}\sum_{j\in E_B}P_{j,t}^{\text{shed}}\cdot\Delta t \tag{4}$$

where $P_{j,t}^{\text{shed}}$ is the load shedding at bus j at period t. E_B is the set of buses and T is the whole repair period. The objective is to minimize the load shedding during the repair process.

2) Distribution system operation constraints

The operation of the distribution system can be described by the linear DistFlow model[9]:

$$\sum_{l\in\sigma(j)}H_{l,t}-\sum_{l\in\delta(j)}H_{l,t}=P_{j,t}^{G}+P_{j,t}^{\text{MPS}}-(P_j^L-P_{j,t}^{\text{shed}}),\forall t\in T,\forall j\in E_B \tag{5}$$

$$\sum_{l\in\sigma(j)}G_{l,t}-\sum_{l\in\delta(j)}G_{l,t}=Q_{j,t}^{G}-(Q_j^L-Q_{j,t}^{\text{shed}}),\forall t\in T,\forall j\in E_B \tag{6}$$

$$V_{i,t}-V_{j,t}-(r_lH_{l,t}+X_lG_{l,t})/V_0\le M(1-Z_{l,t}),\forall t\in T,\forall l\in E_L \tag{7}$$

$$V_{i,t}-V_{j,t}-(r_lH_{l,t}+X_lG_{l,t})/V_0\ge M(1-Z_{l,t}),\forall t\in T,\forall l\in E_L \tag{8}$$

$$V_{\min,j}^2\le V_{j,t}\le V_{\max,j}^2,\forall t\in T,\forall j\in E_B \tag{9}$$

$$0\le P_{j,t}^G\le P_{\max,g}^G,\forall t\in T,\forall j\in E_G \tag{10}$$

$$0\le Q_{j,t}^G\le Q_{\max,g}^G,\forall t\in T,\forall j\in E_G \tag{11}$$

$$-Z_{l,t}S_l^{\max}\le H_{l,t}\le Z_{l,t}S_l^{\max},\forall t\in T,\forall l\in E_L \tag{12}$$

$$-Z_{l,t}S_l^{\max}\le G_{l,t}\le Z_{l,t}S_l^{\max},\forall t\in T,\forall l\in E_L \tag{13}$$

$$0\le P_{j,t}^{\text{shed}}\le P_j^L,\forall t\in T,\forall j\in E_B \tag{14}$$

$$Q_{j,t}^{\text{shed}}=P_{j,t}^{\text{shed}}/pf_j,\forall t\in T,\forall j\in E_B \tag{15}$$

$H_{l,t}$ is the power flow on line j at period t. $\sigma(j)$ is the set of lines at the lower class connected to bus j. $\delta(j)$ is the set of lines at the upper class connected to bus j. $P_{j,t}^G$ is the active power output of DGs at period t. $P_{j,t}^{\text{MPS}}$ is the active power output of MPSs in bus j at period t. P_j^L is the original load at bus j. Q and G denote the reactive power and reactive power flow. V_0 is the reference voltage. $V_{i,t}$ is the voltage of bus j at period t. r_l and X_l are the resistance and reactance of line l. E_l is the set of lines. M is a large constant. $Z_{l,t}$ is a binary variable denoting the status of the line l at period t. $Z_{l,t}$ equals to 1 if line l is available at period t. E_G is the set of DGs. $S_l^{\max}$ is the capacity of line l. pf_j is the power factor at bus j.

Constraints and are the power balance constrains. Constraints and describe the relationship between the voltage and the power flow. Constraint (9) ensures the node voltage will not exceed the acceptable range. Constraints (10) and (11) restrict the output of DGs. Constraints (12) and (13) limit the power flow on the line. Constraints (14) and (15) limit the load shedding at each bus.

3) Topology constraints

The distribution system must remain radiant [10]:

$$\sum_{l\in E_L}Z_{l,t}=n_v-\sum_{j\in R}\eta_{j,t},\forall t\in T \tag{16}$$

$$\sum_{l\in\delta(j)}f_{l,t}-\sum_{l\in\sigma(j)}f_{l,t}=1,\forall t\in T,\forall j\in E_B\setminus R \tag{17}$$

$$1-M\eta_{j,t}\le\sum_{l\in\delta(j)}f_{l,t}-\sum_{l\in\sigma(j)}f_{l,t}\le 1+M\eta_{j,t},\forall t\in T,\forall j\in R \tag{18}$$

$$-MZ_{l,t}\le f_{l,t}\le MZ_{l,t},\forall t\in T,\forall l\in E_L \tag{19}$$

R is the set of potential root nodes. $\eta_{j,t}$ is a binary variable denoting whether node j become root node, which equals to 1 if node j becomes a root node.

4) Repair crew dispatching constraints

The repair crew dispatch is formulated as the travelling salesman model:

$$\sum_{n\in E_F\setminus\{1\}}x_{1,n,c}-\sum_{n\in E_F\setminus\{1\}}x_{n,1,c}=1,\forall c\in E_C \tag{20}$$

$$\sum_{n\in E_F\setminus\{m\}}x_{m,n,c}-\sum_{n\in E_F\setminus\{m\}}x_{n,m,c}=0,\forall c\in E_C,\forall m\in E_F\setminus\{1,ds\} \tag{21}$$

$$\sum_{n\in E_F\setminus\{1,ds\}}x_{ds,n,c}-\sum_{n\in E_F\setminus\{1,ds\}}x_{n,ds,c}=-1,\forall c\in E_C \tag{22}$$

$$\sum_{c\in E_C}y_{m,c}=1,\forall m\in E_F\setminus\{1\} \tag{23}$$

$$y_{m,c} = \sum_{\forall n \in E_{\mathrm{F}} \setminus \{m\}} x_{m,n,c}, \forall m \in E_{\mathrm{F}} \setminus \{1\} \quad (24)$$

$$AT_{m,c} + tr_m + te_{m,n,c} - AT_{n,c} \le M(1 - x_{m,n,c}), \forall m, n \in E_{\mathrm{F}} \setminus \{1\}, \forall c \in E_{\mathrm{C}} \quad (25)$$

$$AT_{m,c} + tr_m + te_{m,n,c} - AT_{n,c} \ge -M(1 - x_{m,n,c}), \forall m, n \in E_{\mathrm{F}} \setminus \{1\}, \forall c \in E_{\mathrm{C}} \quad (26)$$

$$0 \le AT_{m,c} \le My_{m,c}, \forall c \in E_{\mathrm{C}}, \forall m \in E_{\mathrm{F}} \quad (27)$$

$$\sum_{\forall t \in T} t\tau_{m,t} \ge \sum_{\forall c \in E_{\mathrm{C}}} (AT_{m,c} + tr_{m,c} y_{m,c}), \forall m \in E_{\mathrm{F}} \quad (28)$$

$$\sum_{\forall t \in T} t\tau_{m,t} \le 1 - \varepsilon + \sum_{\forall c \in E_{\mathrm{C}}} (AT_{m,c} + tr_{m,c} y_{m,c}), \forall m \in E_{\mathrm{F}} \quad (29)$$

$$z_{m,t} \le \sum_{k=1}^{t} \tau_{m,k}, \forall m \in E_{\mathrm{F}}, \forall t \in T \quad (30)$$

$$Z_{m,t} \le z_{m,t}, \forall m \in E_{\mathrm{F}} \setminus \{1, ds\} \quad (31)$$

E_{C} is the set of repair crews. E_{F} is the set of failure components. Binary variable $x_{m,n,c}$ represents the route of repair crews, which equals to 1 if crew c moves from component m to component n. Binary variable $y_{m,c}$ equals to 1 if crew c has arrived at component m. $AT_{m,c}$ is the arrival time for repair crew c to arrive at component m. tr_m is the repair time for component m. $te_{m,n,c}$ is the travelling time for repair crew c from component m to n. ε is a small constant. $\tau_{m,t}$ is a binary variable judging whether the repair work for component m is finished at period t, which equals to 1 if component m is repaired.

Constraints (20)-(24) ensure that repair crews start from the depot and return to the depot after all components are repaired. Constraints (25)-(27) can calculate the arrival time of each component. Constraints (28) - (31) represent the status of failure components during the restoration.

5) MPS constraints

$$\sum_{n \in E_{\mathrm{mps}} \setminus \{1\}} x_{1,n,c}^{\mathrm{MPS}} - \sum_{n \in E_{\mathrm{mps}} \setminus \{1\}} x_{n,1,c}^{\mathrm{MPS}} = 1, \forall c \in E_{\mathrm{mc}} \quad (32)$$

$$\sum_{n \in E_{\mathrm{mps}} \setminus \{m\}} x_{m,n,c}^{\mathrm{MPS}} - \sum_{n \in E_{\mathrm{mps}} \setminus \{m\}} x_{n,m,c}^{\mathrm{MPS}} = 0, \forall c \in E_{\mathrm{mc}}, \forall m \in E_{\mathrm{mps}} \setminus \{1, ds\} \quad (33)$$

$$\sum_{n \in E_{\mathrm{mps}} \setminus \{1,ds\}} x_{ds,n,c}^{\mathrm{MPS}} - \sum_{n \in E_{\mathrm{mps}} \setminus \{1,ds\}} x_{n,ds,c}^{\mathrm{MPS}} = -1, \forall c \in E_{\mathrm{mc}} \quad (34)$$

$$\sum_{c \in E_{\mathrm{mc}}} y_{m,c}^{\mathrm{mps}} \le 1, \forall m \in E_{\mathrm{F}} \setminus \{1\} \quad (35)$$

$$y_{m,c}^{\mathrm{MPS}} = \sum_{\forall n \in E_{\mathrm{mps}} \setminus \{m\}} x_{m,n,c}^{\mathrm{MPS}}, \forall m \in E_{\mathrm{mps}} \setminus \{1\}, \forall c \in E_{\mathrm{mc}} \quad (36)$$

$$AT_{m,c}^{\mathrm{MPS}} + t_m^{\mathrm{MPS}} + te_{m,n,c}^{\mathrm{MPS}} - AT_{n,c}^{\mathrm{MPS}} \le M(1 - x_{m,n,c}^{\mathrm{MPS}}), \forall m, n \in E_{\mathrm{mps}} \setminus \{1\}, \forall c \in E_{\mathrm{mc}} \quad (37)$$

$$AT_{m,c}^{\mathrm{MPS}} + t_m^{\mathrm{MPS}} + te_{m,n,c}^{\mathrm{MPS}} - AT_{n,c}^{\mathrm{MPS}} \ge -M(1 - x_{m,n,c}^{\mathrm{MPS}}), \forall m, n \in E_{\mathrm{mps}} \setminus \{1\}, \forall c \in E_{\mathrm{mc}} \quad (38)$$

$$0 \le AT_{m,c}^{\mathrm{MPS}} \le My_{m,c}^{\mathrm{MPS}}, \forall c \in E_{\mathrm{mc}}, \forall m \in E_{\mathrm{mps}} \quad (39)$$

$$\sum_{\forall t \in T} t\lambda_{m,t}^{\mathrm{ar}} \ge \sum_{\forall c \in E_{\mathrm{mc}}} AT_{m,c}^{\mathrm{MPS}}, \forall m \in E_{\mathrm{mps}} \quad (40)$$

$$\sum_{\forall t \in T} t\lambda_{m,t}^{\mathrm{le}} \ge \sum_{\forall c \in E_{\mathrm{mc}}} (AT_{m,c}^{\mathrm{MPS}} + t_{m,c}^{\mathrm{MPS}} y_{m,c}^{\mathrm{MPS}}), \forall m \in E_{\mathrm{mps}} \quad (41)$$

$$h_{m,t} = \sum_{s=1}^{t} \lambda_{m,s}^{\mathrm{ar}} - \sum_{s=1}^{t} \lambda_{m,s}^{\mathrm{le}} \quad (42)$$

$$0 \le P_{m,t}^{MPS} \le h_{m,t} P_{\max}^{\mathrm{MPS}}, \forall m \in E_{\mathrm{mps}} \quad (43)$$

$$P_{m,t}^{MPS} = 0, \forall m \in E_{\mathrm{B}} \setminus E_{\mathrm{mps}} \quad (44)$$

E_{mps} is the set of the node which can be connected with the MPS. t_m^{MPS} is the work time for the MPS at node m. Binary variable $\lambda_{m,t}^{\mathrm{ar}}$ equals to 1 if the MPS arrives at component m at period t. $\lambda_{m,t}^{\mathrm{le}}$ equals to 1 if the MPS leaves from component m at period t. $h_{m,t}$ is a binary variable denoting whether MPS is in the discharge state at period t. Constraints (43) and (44) limit the power output of the MPS.

C. Copeland Ranking Method

The cumulative distribution function (CDF) of the repair moment of can be obtained by solving the above restoration model. The modified Copeland method in [6] is introduced to rank the component importance. Defining the percentiles of the CDF as φ characteristics, the Copeland score is obtained by follows:

$$S_{m,n,k} = \begin{cases} S_{m,n,k-1} + 1 & q_{\mathrm{k}}(m) \succ q_{\mathrm{k}}(m) \\ S_{m,n,k-1} + 0.5 & q_{\mathrm{k}}(m) = q_{\mathrm{k}}(m) \\ S_{m,n,k-1} & q_{\mathrm{k}}(m) \prec q_{\mathrm{k}}(m) \end{cases} \quad (45)$$

$$S_m = \sum_{m,n \in E_{\mathrm{L}}} S_{m,n,\varphi} \quad (46)$$

where $S_{m,n,k}$ is the Copeland score between component m and n. $q_{\mathrm{k}}(m)$ represents the k^{th} percentile of the CDF of the repair moment of component m. S_m is the final score of component m. The symbol $\succ$ indicates that the component is repaired earlier.

III. Component Impotance Assessment

The whole process can be divided in three sub-process and the flow chart is shown in Fig. 1.

A. Component Failure Scenarios Sampling

According to the wind speed and component failure rate data, parameters in (1) can be determined. Then the failure rate and probability can be calculated by (2)-(3). Based on the component failure probability under wind storm, non-sequential Monte Carlo method is used to sample the component failure scenarios. R_l is a random variable on the interval [0,1], which is used to determine the status of component l in a fault scenario. Considering the component failure probability $q_{ij,\mathrm{wind}}$, the sample process is as below:

$$\begin{cases} S_l = 1, & q_{l,\mathrm{wind}} < R_l \le 1 \\ S_l = 0, & 0 \le R_l \le q_{l,\mathrm{wind}} \end{cases} \quad l \in E_{\mathrm{L}} \quad (47)$$

where $q_{l,\mathrm{wind}}$ is the failure probability of line l under wind storms. S_l is a binary variable denoting the status of the component l, which equals to 0 if the component is destroyed.

B. Repair Crew Dispatching Scheduling

The traveling time between components is calculated by Dijkstra algorithm in advance. In each scenario, failure components are determined. The repair sequence and the repair time can be obtained by solving the proposed post-disaster restoration model.

C. Copeland Score Calculation

After obtaining a series of component repair sequences and the repair period of each component, the CDF of the component repair period can be calculated. Then Copeland score of each component can be obtained by the above method. Finally, components are ranked according to their scores. The component with a high score is more important for the distribution system.

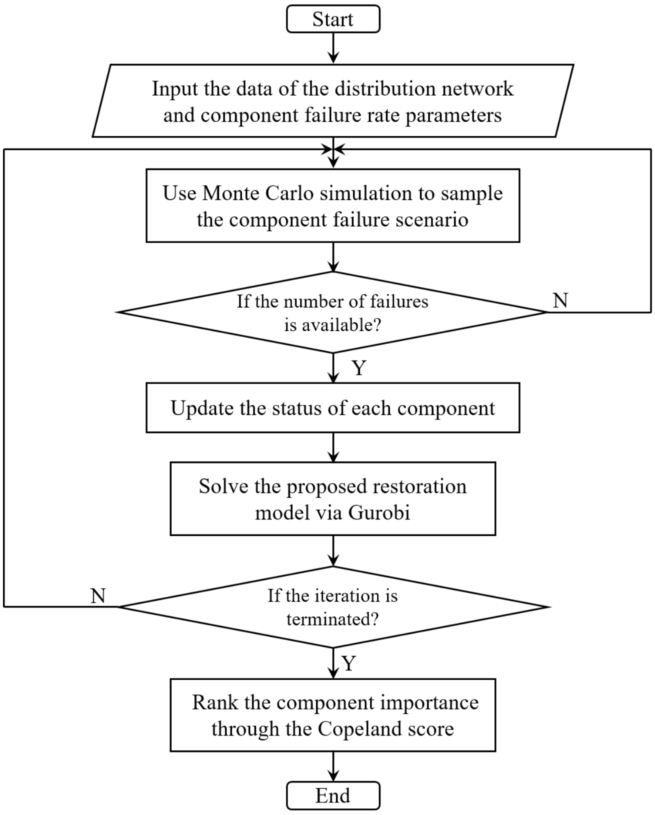

Fig. 1. The flow chart of component importance assessment

IV. Case Study

The component importance assessment method is applied on IEEE-33 node distribution test system, which is shown in Fig.2. There are 33 nodes, 32 lines and 5 tie lines in this system. Four DGs are installed in different nodes. The maximum output of each DG is 200kW. The depot is located at node 10. There are two repair crews and one MPS in this depot. The maximum output of the MPS is 200kW. The repair time of each component is set as 1h.

The parameters for calculating the component failure rate are as follows[7]: $\gamma_1 = 0.21$, $\gamma_2 = 0.49$, $\gamma_3 = 9.83$, $\omega_{crit} = 8\mathrm{m/s}$, $\lambda_{\mathrm{norm}} = 0.053$. The components in this paper are lines. The components are shown in TABLE I.

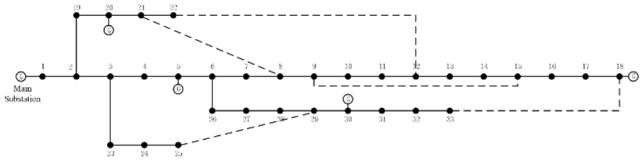

Fig. 2. IEEE-33 node distribution test system

TABLE I
THE NUMBER OF COMPONENTS

Number	Component	Number	Component
1	<1-2>	20	<20-21>
2	<2-3>	21	<21-22>
3	<3-4>	22	<3-23>
4	<4-5>	23	<23-24>
5	<5-6>	24	<24-25>
6	<6-7>	25	<6-26>
7	<7-8>	26	<26-27>
8	<8-9>	27	<27-28>
9	<9-10>	28	<28-29>
10	<10-11>	29	<29-30>
11	<11-12>	30	<30-31>
12	<12-13>	31	<31-32>
13	<13-14>	32	<32-33>
14	<14-15>	33	<21-8>
15	<15-16>	34	<9-15>
16	<16-17>	35	<12-22>
17	<17-18>	36	<18-33>
18	<2-19>	37	<25-29>
19	<19-20>		

565 scenarios are selected by the Monte Carlo simulation. The repair sequence an repair time in each scenario are obtained by solving the restoration model. The CDF of part of components is shown in Fig.3. The Copeland score of each component is shown in Fig.4 As can be seen from Fig.3, the cumulative probability of line <32-33> is the highest in three components. It means that <32-33> is repaired earlier than <13-14> and <11-12> under the same probability. It can be observed from Fig.3 that <32-33> ranks higher than other components. The result shows that the component importance is related to the load at each node. In the test system, the load and weight of nodes 8, 24, 25 and 32 are larger than those of other nodes. Therefore, lines connecting with these nodes, such as line 32, 24 and 7 are relatively important. Besides, the

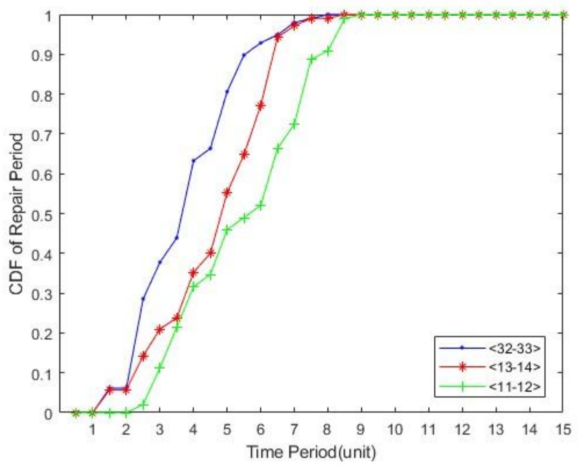

Fig. 3. CDF of repair period of <32-33>, <13-14>, <11-12>

component location will also affect the importance of the component. Lines 32, 24 and 7 are adjacent to tie lines. In the post-disaster restoration process, network reconfiguration plays an important role in reducing the load loss. The distribution system operator can divide the distribution network into multiple islands supported by DGs to restore the critical load. Therefore, lines near tie lines are also important. The result shows that the proposed method can effectively identify the important component and rank the componet importance.

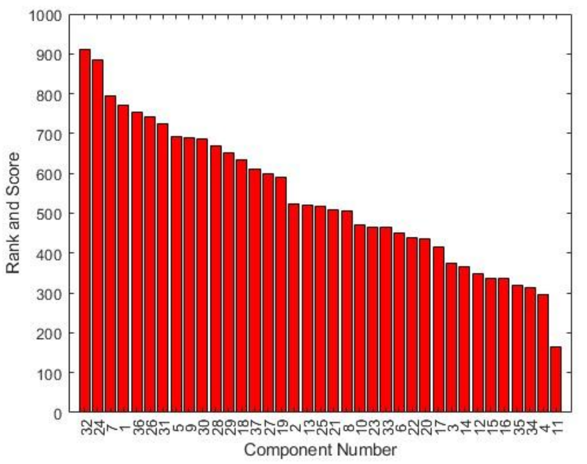

Fig. 4. The rank and score of the components

V. Conclusion

Considering the role of flexible resources in distribution network, this paper proposes a component importance assessment method for the distribution system to enhance the system resilience. Based on the component failure model, the non-sequential Monte Carlo simulation method is used to sample fault scenarios. For each scenario, the distribution system operator minimizes the load loss through repair crew dispatch, MPSs dispatch, DGs scheduling and network reconfiguration. The post-disaster restoration problem is formulated as a mixed integer linear programming model, which can be solved directly by commercial solvers. According to the repair sequence and repair time for each component, the Copeland ranking method is used to score and rank the component importance. Numerical results show that the proposed method can effectively identify important components in the distribution system. The ranking result will be helpful for pre-disaster component reinforcement and post-disaster fast recovery.

Acknowledgment

This work was supported by State Grid Shandong Electric Power Company Sci & Tech Project (5206002000U7).

References

[1] Bie ZH, Lin YL, Li GF, et al, " Battling the Extreme: A Study on the Power System Resilience," Proceedings of the IEEE, vol. 105(7), pp.1253-1266, 2017.

[2] Zhao YX, Liu SY, Lin ZZ, et al, "Identification of critical lines for enhancing disaster resilience of power systems with renewables based on complex network theory," IET Generation, Transmission & Distribution, vol. 14(20), pp. 4459-4467,2020.

[3] Espinoza S, Poulos A, Rudnick H, et al, "Risk and Resilience Assessment With Component Criticality Ranking of Electric Power Systems Subject to Earthquakes," IEEE Systems Journal, vol. 14(2), pp. 2837-2848, 2020.

[4] Fu T, Wang DX, Fan XY, et al, "Component Importance and InterdependenceAnalysis for Transmission, Distribution and Communication Systems," CSEE Journal of Power and Energy Systems, vol. 8(2), pp. 488-498, 2022.

[5] Xie HP, Sun XT, Fu W, et al, "Risk management for integrated power and natural gas systems against extreme weather: A coalitional insurance contract approach," Energy, vol.263, 2023.

[6] Li GF, Huang GC, Bie ZH, et al, "Component importance assessment of power systems for improving resilience under wind storms," Journal of Modern Power Systems and Clean Energy, vol. 7(4), pp. 676-687, 2019.

[7] Alvehag K, Soder L, "A Reliability Model for Distribution Systems Incorporating Seasonal Variations in Severe Weather," IEEE Transactions on Power Delivery, vol. 26(2), pp. 910-919, 2011.

[8] Zio E, Piccinelli R, "Randomized flow model and centrality measure for electrical power transmission network analysis," Reliability Engineering & System Safety, vol. 95(4), pp. 379-385, 2010.

[9] Lin YL, Chen B, Wang JH, "A Combined Repair Crew Dispatch Problem for Resilient Electric and Natural Gas System Considering Reconfiguration and DG Islanding," IEEE Transactions on Power Systems, vol. 34(4), pp. 2755-2767, 2019.

[10] Ding T, Lin YL, Li GF, et al, " A new model for resilient distribution systems by microgrids formation," IEEE Transactions on Power Systems, vol. 32(5), pp. 4145-4147, 2017.