Preventive Power Outage Estimation Based on A Novel Scenario Clustering Strategy

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Contributions

- An optimal three-phase distribution system restoration model is established considering mobile energy resources (MERs) and the repair crews (RCs).
- A novel scenario clustering algorithm is proposed to reduce the scenario scale based on the accumulated nodal unserved load.
- The integration of MERs and RCs has been proved to significantly reduce the unserved load, and the representative scenarios can effectively preserve information of original scenarios.

Three-phase Distribution System Restoration Model

Objective function

$$min.\ \sum_{t\in\Omega_T}\Delta t\sum_{i\in\Omega_B}\sum_{\phi\in\Omega_\Phi}P_{i,\phi,t}^{eens}$$

Power flow constraints

$$P_{i,\phi,t}^{MT}+P_{i,\phi,t}^{PV}+P_{i,\phi,t}^{MER}-P_{i,\phi,t}^{D}+P_{i,\phi,t}^{eens}=\sum_{k\in\delta(i)}P_{ik,\phi,t}-\sum_{j\in\pi(i)}P_{ji,\phi,t}$$

$$v_{j,\phi,t}=v_{i,\phi,t}-\Delta v_{ij,\phi,t}-2(\tilde{\boldsymbol{r}}_{ij,\phi}\boldsymbol{P}_{ij,t}+\tilde{\boldsymbol{x}}_{ij,\phi}\boldsymbol{Q}_{ij,t})$$

Mobile energy resource allocation

$$\sum_{i\in\mathrm{N_m}}y_{m,i,t}\le 1,\ \forall m\in\Omega_M$$
$$\sum_{m\in\Omega_M}y_{m,i,t}\le Cap_i,\ \forall i\in\cup_{m\in\Omega_M}\mathrm{N_m}$$
$$z_{m,t}=1-\sum_{i\in\mathrm{N_m}}y_{m,i,t},\ \forall m\in\Omega_M$$
$$y_{m,i,t+\tau}+y_{m,j,t}\le 1,\forall m\in\Omega_M,\forall i,j\in\mathrm{N_m},\ \forall\tau\le t_{m,i,j}^{tr},\ \forall t+\tau\le|\Omega_\mathrm{T}|$$

Repair crew scheduling

$$\gamma_{ij,t}\le\frac{\sum_{\tau=1}^{t}y_{m,ij,t}}{t_{m,ij}^{rc}},\forall m\in\Omega_{RC},\forall ij\in\Omega_F$$
$$\gamma_{ij,t}\le\gamma_{ij,t+1},\forall ij\in\Omega_F$$

K-means-based Scenario Clustering

Algorithm 1: Scenario Clustering

1. Scenario generation: Enumerate all possible faulted line scenarios based on the OPM outputs.
2. Initialization: For each $s\in\Omega_S$, compute:

$$\boldsymbol{E}^s\in argmin\ \sum_{t\in\Omega_T}\Delta t\sum_{i\in\Omega_B}\sum_{i\in\Omega_\Phi}P_{i,\phi,t}^{eens}$$

3. *K*-means clustering:
3.1. Select a proper k.
3.2. Run the k-means algorithm by using the "sklearn" package. The algorithm aims to minimize the within-cluster sum of squares (WCSS):

$$WCSS\in argmin\ \sum_{i=1}^{k}\sum_{s\in\Omega_{Si}}\|\boldsymbol{E}^s-\boldsymbol{\mu}_i\|^2$$

where $\boldsymbol{\mu}_i$ is the centroid of cluster i.
3.3. Update the probability of clusters.

$$p(i)=\sum_{s\in\Omega_{Si}}p(s)$$

Numerical Simulations

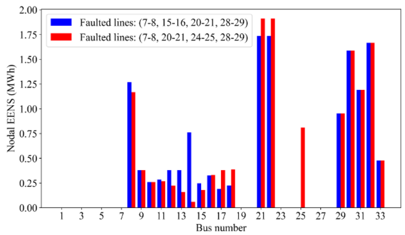

Fig. 1. Example of two nodal unserved load profiles.

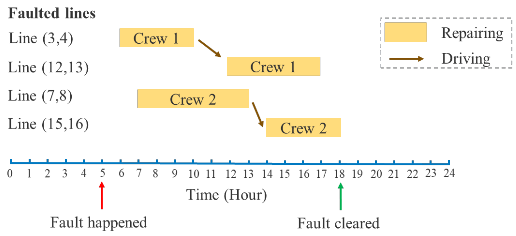

Fig. 3. RC schedule.

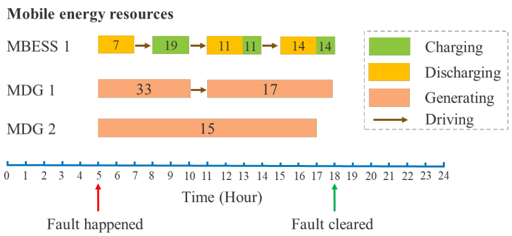

Fig. 4. MER allocation.

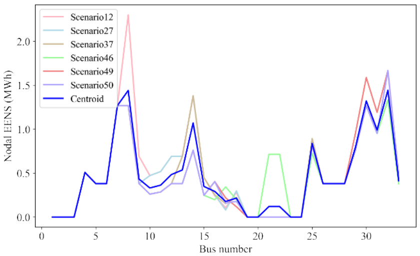

Fig.2. Original scenarios and the centroid of Cluster 8.

Table 1 Comparison of the original and clustered scenarios without MERs.

Total EENS (MWh)	Unserved load ratio (%)	Original probability (%)	Clustered probability (%)
0 - 5	0 - 4.77	1.59	0
5 - 10	4.77 - 9.55	20.63	28.57
10 - 15	9.55 - 14.32	27.78	23.82
15 - 20	14.32 - 19.09	36.51	37.30
20 - 25	19.09 - 23.87	11.90	10.32
25 - 30	23.87 - 28.64	1.59	0

Table 2 Comparison of the original and clustered scenarios with MERs.

Total EENS (MWh)	Unserved load ratio (%)	Original probability (%)	Clustered probability (%)
0 - 5	0 - 4.77	37.30	37.30
5 - 10	4.77 - 9.55	23.81	26.98
10 - 15	9.55 - 14.32	36.51	34.92
15 - 20	14.32 - 19.09	2.38	0.79
20 - 25	19.09 - 23.87	0	0
25 - 30	23.87 - 28.64	0	0

Conclusions

- The numerical simulation verifies that the representative scenarios can maintain the characteristics of the original scenarios.
- The improvement of the MER integration in the restoration process is also quantitively evaluated.

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