APPENDIX

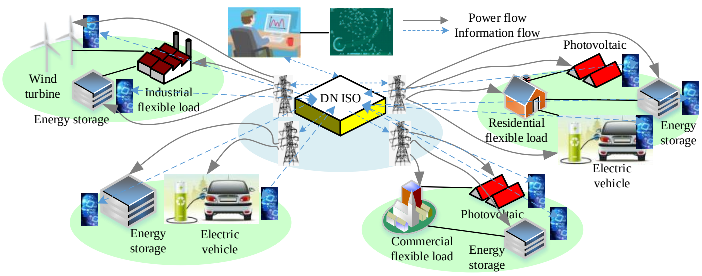


Fig. A1. Structure diagram of the distribution network

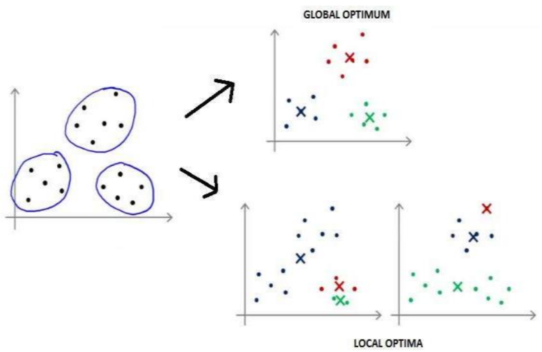


Fig. A2. Feasible solution space falling into local optimum

As shown in Fig. A2, the global optimal solution is obtained by selecting an optimal solution from the adjacent solution space of the current solution and replacing it with the current solution. With the increasing number of variables and change of constraints, the search space and direct may change, then the problem may fall into local optimum.

TABLE A1

RECONSTRUCTION STRATEGIES OF DISTRIBUTION NETWORK

Number	Reconstruction strategies	Impactor factor
Infrastructure construction and reinforcement		
X_1	Replace old equipment	λ_F
X_2	Insulation modification of overhead bare conductor	λ_F
X_3	Add section switch of overhead line	N_S
X_4	Strengthen measures to protect equipment against natural disasters	λ_F
X_5	Provide addition transferring line	N_Z
Construction and reinforcement of modern facilities		
X_6	Add two-remotes terminals	N_{De}
X_7	Add three-remotes terminals	N_{Ds}
X_8	Closed loop operation reconstruction of cable line	T_1、T_2、T_3
X_9	Access DG for power supply	N_Z
Improvement of technology and management		
X_{10}	Strengthen daily inspection to prevent damage from external forces	λ_F
X_{11}	Improve fault location technology	T_3
X_{12}	Isolate and repair according to standard time	T_1, T_2, T_3
X_{13}	Strengthen the technical level of live fire connection	λ_J
X_{14}	Strengthen the of integration and management of outage project	λ_J, T_J

*N_S, N_Z, N_{De}, N_{Ds}, λ_J, T_J represent the number of segments, transferring rate, number of two- and three-remote terminals, pre-arranged outage and time of feeders.

The data generation process for DBN based correlation constraint is presented in Fig. A3.

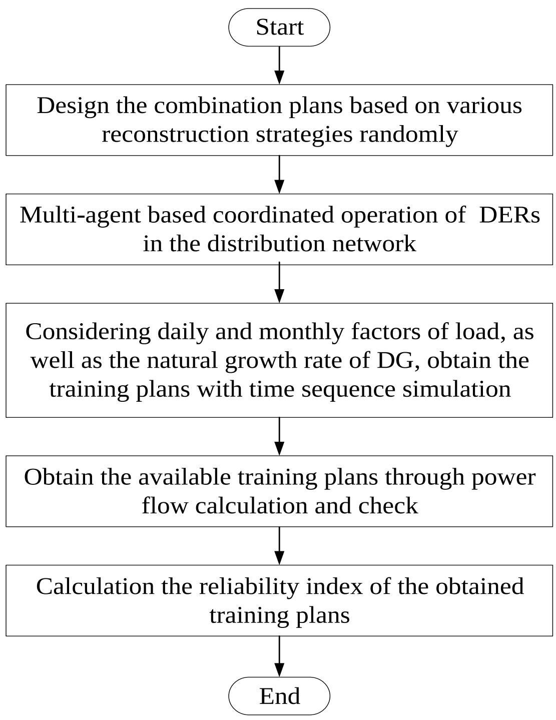


Fig. A3. Data generation process

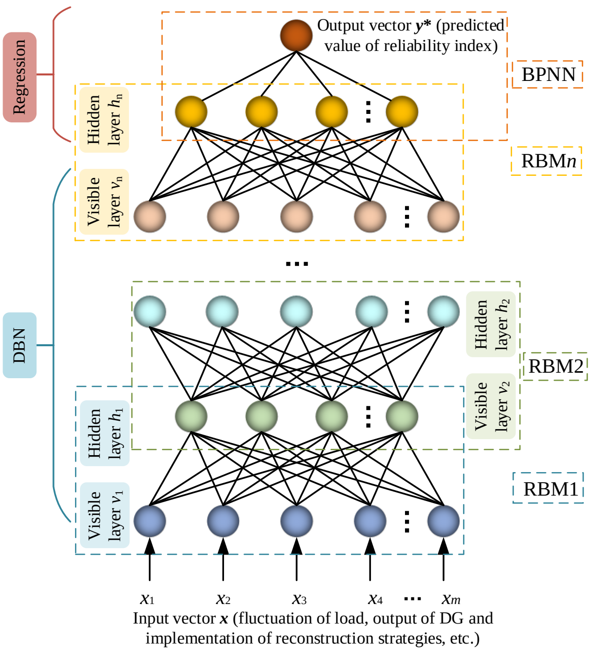


Fig. A4. Structure of DBN

The generation process of the correlation mining algorithm is presented in Fig. A5.

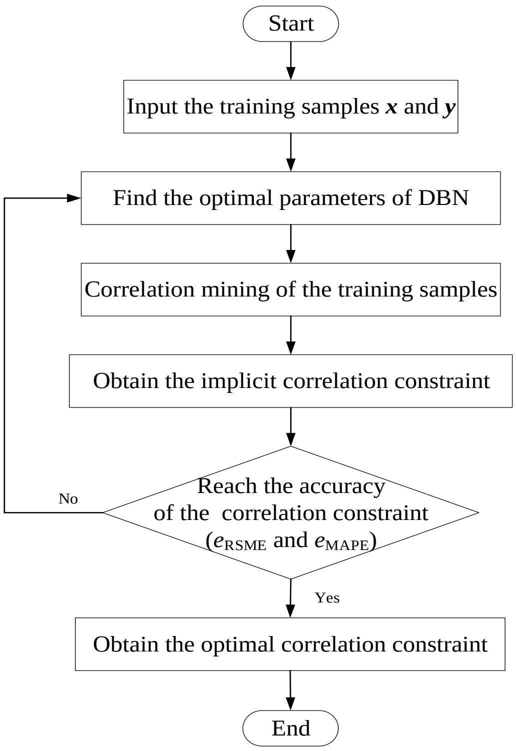


Fig. A5. The generation process of the correlation mining algorithm based constraint

The solution process of the investment optimization model is shown as Fig. A6.

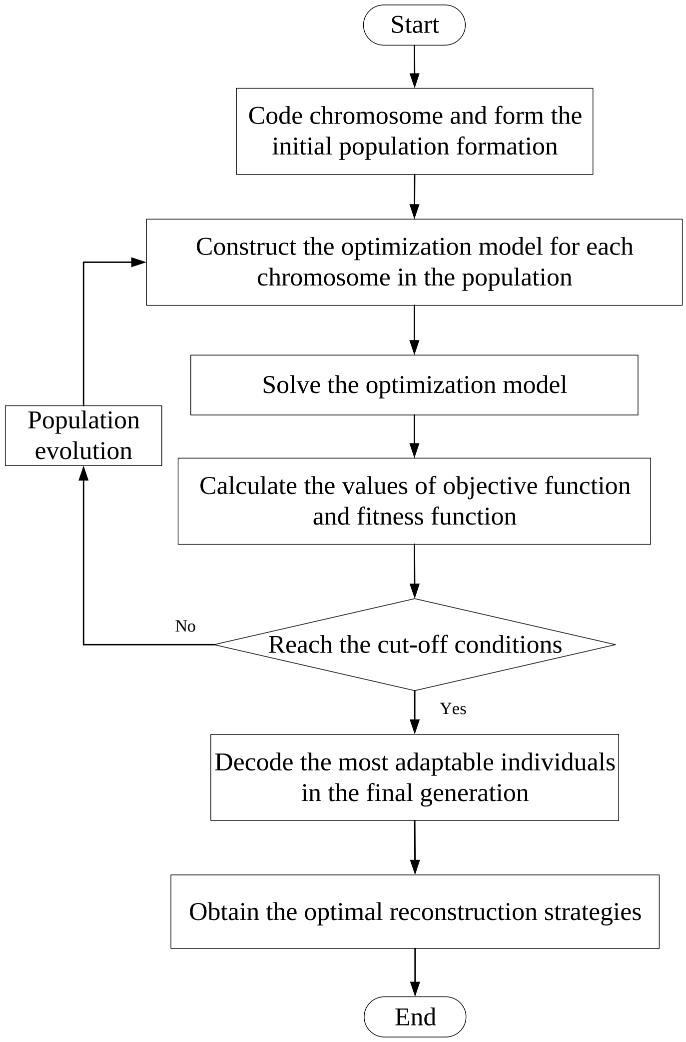


Fig. A6. Solving process of the optimization model

The structure of the initial system is shown as Fig. 3. As shown in Fig. 3, the regional distribution network is powered by two 35kV substations. The distribution network can be divided into two areas: R1 and R2. R1 is adopted as the test system, which includes DG, energy storage and flexible load. DGs are installed at buses 7, 15, 28 with 0.2MW, 1.5MW and 0.3MW, respectively. Switches are installed at buses 1, 2, 4, 7, 11, 14, 24, 30. A three-remote terminal is installed at bus 7. The system is divided into 4 sections: L1, L2, L3 and L4. The values of C^{EU} of residential, commercial and industrial users are respectively

7.3, 6.4, 5.2 ¥ /kWh. The rate of return on investment is 10%. The parameters of the initial DN system and various reconstruction strategies are shown in Tab. A2.

TABLE A2

INVESTMENT COST PARAMETERS OF RECONSTRUCTION STRATEGY

Number	C^{In}/ (× 10^4 ¥)	Ratio of C^{Op} to C^{In} (%)	m	Number	C^{In}/ (× 10^4 ¥)	Ratio of C^{Op} to C^{In} (%)	m
X_1	13.2/km	3	20	X_8	25/km	4	20
X_2	14.7/km	3	15	X_9	400/MW	4	20
X_3	2.5	3	15	X_{10}	26	—	—
X_4	11.4/km	4	15	X_{11}	37	—	—
X_5	15.6/km	4	20	X_{12}	28	—	—
X_6	2	4	20	X_{13}	40	—	—
X_7	3.5	4	20	X_{14}	22	—	—

The parameter settings of DBN are shown in Tab. A3.

TABLE A3

PARAMETER SETTINGS OF DBN

Parameters	Value
Learning rate of RBM	0.0005
Training batches of RBM	200
Training epochs of RBM	200
Learning rate of BP neural network (BPNN)	0.001
Training batches of BPNN	150
α_1	0.9
α_2	0.999
ε	10^{-8}

*α_1, α_2 and ε are the parameters of Nadam optimizer.

Tab. A4 shows the total e_{MAPE} and e_{RSME} of the 195 scenarios, which demonstrate that the proposed method outperforms other algorithms on the correlation mining of reconstruction strategies and EENS index.

TABLE A4

PREDICTION ERRORS OF DIFFERENT METHODS

Method	e_{MAPE}/%	e_{RSME} /MW	Solving time (s)
Method proposed in this paper	6.41	0.0445	533
Traditional DBN	7.47	0.0519	545
DNN	8.23	0.0583	558
LSTM	10.61	0.0709	553
BPNN	16.53	0.1095	384

Fig. A7 and Fig. A8 illustrate the values of e_{MAPE} and e_{RSME} of different 13 scenario set.

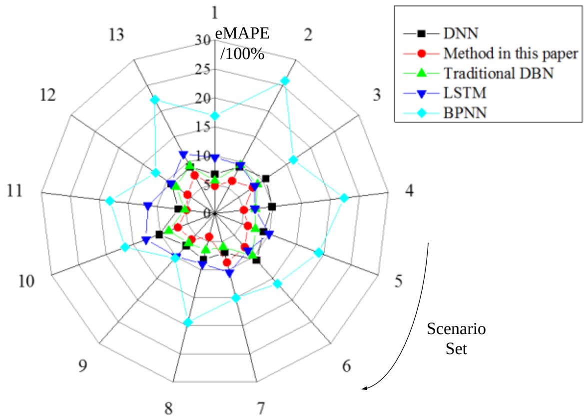


Fig. A7 Values of eMAPE of different scenario set

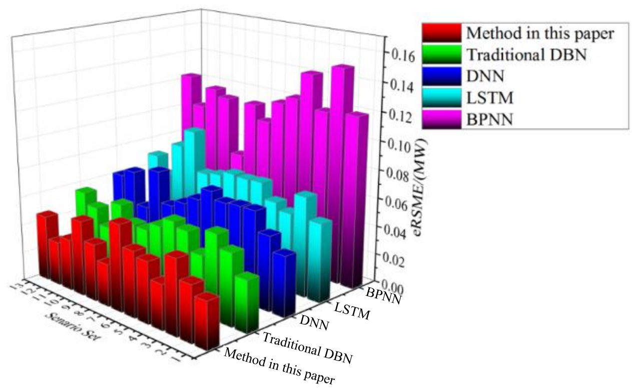
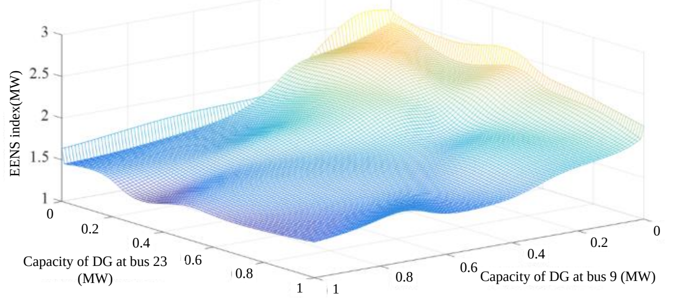
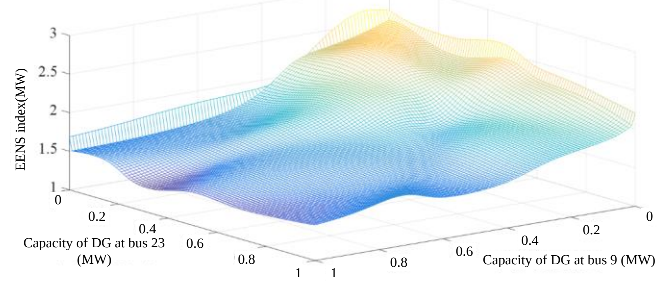


Fig. A8 Values of eRSME of different scenario set

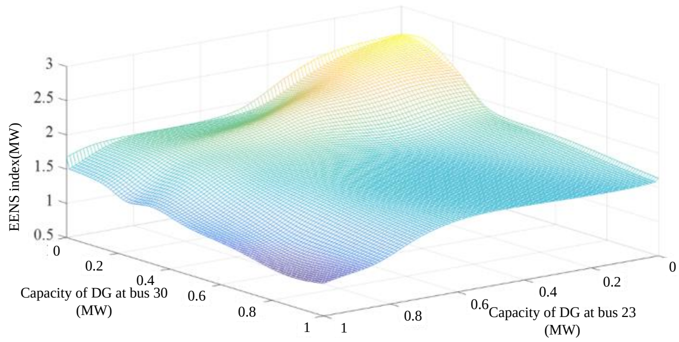
Through the DBN-based correlation mining, the EENS index can be predicted under the reconstruction plans as shown in Fig. A9.



(a) Values of EENS index with DG at bus 9 and 23 (both remote terminals installed at bus 9 and 26)



(b) Values of EENS index with DG at bus 9 and 23 (no remote terminals installed at bus 9 or 26)



(c) Values of EENS index with DG at bus 23 and 30 (both remote terminals installed at bus 9 and 26)

Fig. A9. Values of EENS index with different reconstruction plans

The optimal reconstruction plans with different objectives and constraints in Tab. 2 can be illustrated in Fig. A10.

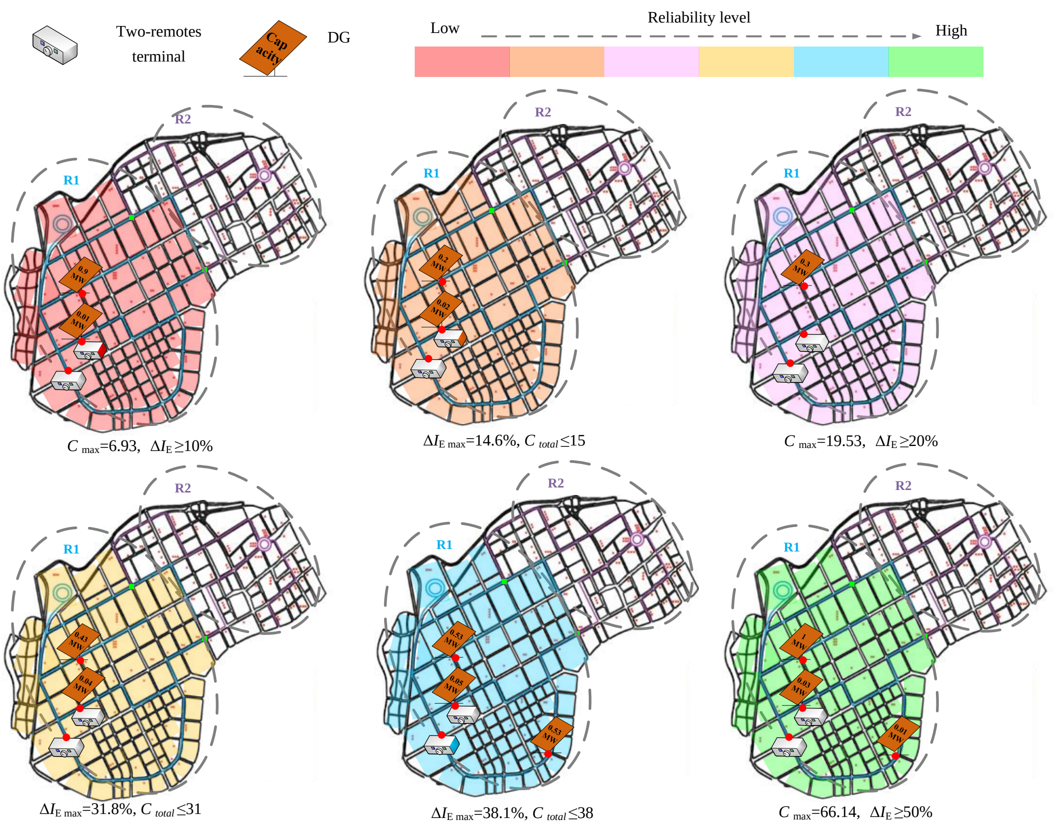


Fig. A10. Optimal reconstruction plans with different objectives and constraints in Tab. 2