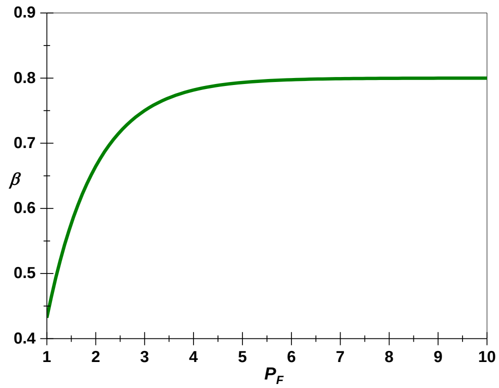
Appendix A Extended references: Table A and Fig. A

TABLE A
CLASSIFICATION OF POWER FAILURE USERS

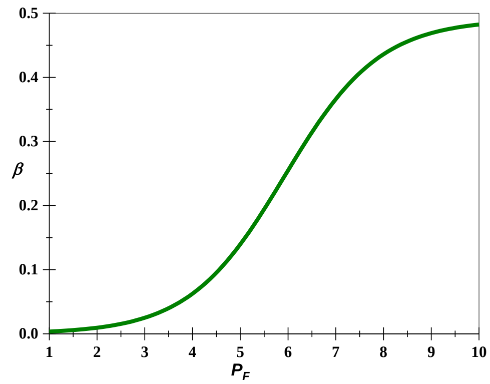
Type	Outage Time	Location
A	T_A=T_{dw}+T_g	Customers Lied in Up-Stream Part of Failure Point
B	T_B=T_{dw}+T_g+T_z	Customers Lied in Down-Stream Part of Failure Point and be Transferred
C	T_C=T_{dw}+T_{dn}+T_x	Customers Lied in Down-Stream Part of Failure Point and not be Transferred, Failed user in failure point

where T_A,T_B, and T_C represent the total outage time of various users, T_{dw}, T_n, T_g, T_z, and T_x represent failure locating time, failure isolating time, load transfer time, and failure repairing time, respectively.

Figure A: Relationship between β and P_F



a. Relationship between β and P_F in line fault



b. Relationship between β and P_F in switch fault

Fig. A. Relationship between β and P_F

From Fig. A(*a*), the value of β will increase as the number of feed segments(P_F) increases until β certain limit in the region. From Fig. A(*b*), the change trend of β with P_F is similar to the Sigmoid function.

Appendix B An Example (and advantage) of the proposed reliability estimation method applied in a case study for optimal planning of distribution network

The influence of most planning measures on the system reliability index is reflected by changing the calculated parameters. For example, insulation of overhead line decreases λ_k, newly added segment switch increases P_F, newly added tie line or distributed power supply increases P_Z, and cable closed-loop operation reduces T_{dw}, T_g, T_z, etc. Therefore the proposed algorithm is suitable for embedded distribution network planning and can improve the solution quality of the optimization model by virtue of explicit calculation. Here, the optimal section planning of overhead line is taken as an example to illustrate.

The classical optimal economic benefit programming model can be expressed in the following form:

$$\begin{cases} \min\ f_{opt}(x_{opt}) = C_{inv} + C_{ens} \\ g(x_{opt}) = 0 \\ h(x_{opt}) \le 0 \end{cases}$$

In the formula, x_{opt} is the decision variable, which refers to the optimal number and position of segmented switches. The objective function $f_{opt(xopt)}$ includes the switching investment cost and the system power failure cost. G (x_{opt}) is the equation constraint of the model, namely the calculation process of reliability index; H (x_{opt}) is an inequality constraint, and the upper limit of line segment can be set according to the guideline.

A feeder is selected from the example distribution network for optimal calculation. The topology structure, line length and node capacity of feeder are shown in figure B. This feeder topology belongs to the second topology type. The fault rate of the circuit is 0.065 times/year and the repair time is 5h. The fault rate of sectional switch and fuse is 0.006 times/year and the repair time is 4h. The fault rate of the distribution transformer is 0.015 times/year and the repair time is 10h. In addition, the maintenance rate of the line is 0.2 times/year, and the maintenance time is 4h. Tdw, Tdn, Tg, and Tz were all set at 0.5h. The installation cost of sectional switches is set at RMB 60,000 / unit, and the cost of unit power failure loss is set at RMB 6.5 /kWh.

The installation cost of sectional switches is set at RMB 60,000 / unit, and the cost of unit power failure loss is set at RMB 6.5 /kWh. After the optimal number of switches is determined, the feasible solution space of the location layout problem has been greatly reduced (if each line can be equipped with sectionalized switches, the feasible solution space will be reduced from 226 to 263, about 104 times). At this time, the analytical method and heuristic algorithm can be used to better deal with this problem. Genetic algorithm (GA) was adopted to solve the problem for 100 times before and after the space reduction of feasible solutions. The comparison of calculation results is given in Table B.

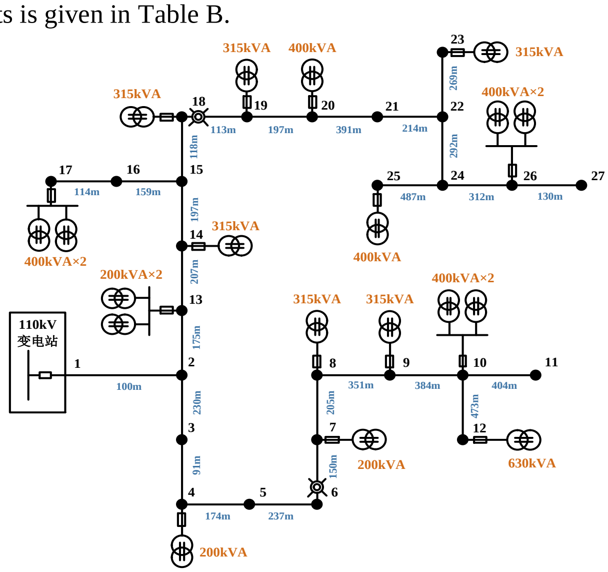


Fig. B. Feeder electrical wiring diagram

TABLE B
COMPARISON OF OPTIMIZATION SOLVING RESULTS

	Algorithm	Population	Iteration	Quality(10^4)	Stability	Time(s)
Consider proposed algorithm	ENUM	—	—	8.17	—	234.15
	GA	10	10	8.42	0.18	2.12
	GA	20	20	8.21	0.61	16.69
	GA	50	100	8.17	0.99	152.4
Not consider proposed algorithm	ENUM			—		
	GA	10	10	10.57	0.00	2.35
	GA	20	20	9.54	0.02	15.82
	GA	50	100	8.25	0.44	161.8

It can be seen from Table B that GA with the same optimization parameters significantly improves the solution quality and stability of the model after considering the algorithm in this paper. In engineering practice, the enumeration method can even be used to ensure the global optimality of the results. And this result is obtained under the condition that only one feeder and only one decision variable is considered, when the initial feasible solution space is further increased (for example, the scale of the distribution network is expanded, or candidate planning measures are increased), the above advantages will undoubtedly become more obvious.