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Research and Simulation of IBPSO-based Fault Location in Power Distribution Network adopting DG

Wang Ying¹, Shi Zhan¹, Kang Zhongmiao¹, Li Xingnan¹

¹Power Dispatching Control Center, Guangdong Power Grid, Guangzhou, 510600, China

Abstract: By analyzing the system structure of power distribution network, the paper summarizes the defects suffered by traditional binary particle swarm optimization (BPSO) and studies the application of improved BPSO (IBPSO) in fault location in power distribution network adopting distributed generation (DG). The standard BPSO is improved by introducing compression factor and Linearly Decreasing Inertia Weight (LDIW), which achieves the improvement on the convergence and fault tolerance. Also, with the application of the new algorithm in new field, the coding mode in DG power distribution network is improved and optimized. Simulation experiment is performed to rationally validate the feasibility of the new algorithm and gains the satisfactory results, which provides better technical space for system management of power distribution network as well as achieves the popularization and promotion of DG power distribution network in modern society.

1. Introduction

With the ever-increasingly higher urbanization degree in modern society, infrastructure construction of power system becomes important for meeting the living and production demand of urban population. The enlarged scale and improved structural complexity of power distribution network are accompanied by increased fault problems. Whether various feeder terminal units (FTUs) receive rational fault acquisition plays a significant role in the administration of power distribution network section. Against this background, how to locate fault in power distribution network is the core to improving power system automation as precise fault location can effectively increase the reliability of power supply. Up to now, there are two common technical methods to locate fault in power distribution network. 1) Direct location method. It determines fault based on fault information and network topology structure and analyzes fault based on matrix analysis. It boosts the advantage of quick speed and high precision while suffers limited fault-tolerant ability. 2) Indirect location method. Genetic Algorithm (GA) is used to analyze the distortion of fault information. However, it cannot support real-time location on fault and relevant system operation cannot be completed without professionals.

Particle Swarm Optimization (PSO) is one of modern intelligent algorithms. In calculation principle, it describes flock behavior using graphics. The memory and feedback mechanism ensure its high-efficient and precise searching. It boosts the advantages of quick calculation speed, and good large-scale mathematical optimization effect. Compared with GA, PSO features simpler parameter setting, more precise implementation approach, higher searching sensitivity and good convergence. However, there are some disadvantages, e.g. it cannot be applied to the calculation of many local extremums point function, the result exhibits obvious prematurity phenomenon, it is easy to be affected by local optimum and is unable to acquire function optimal point ^[1]. Specific to the



prematurity phenomenon, the paper firstly combines PSO with adaptive mutation strategy and optimizes the original PSO, which achieves the precise fault location in power distribution network and contributes to the infinite increase in the probability to get globally optimal solution.

2. Improvement of BPSO

2.1 Principle of BPSO algorithm

Binary Particle Swarm Optimization (BPSO) has always been the basis to support calculation of traditional power distribution network system. The paper makes improvement on the algorithm by introducing the compression factor and Linearly Decreasing Inertia Weight (LDIW), which can achieve global optimization of algorithm and quickens the convergence ability. Most modern power source structures are distributed, of which the structural stability can be greatly optimized relying on new fault location method^[2].

During the operation, it is requested to solve the 0 and 1 issue in computer field. For binary particle swarm, all particles can be expressed as 0 and 1, leading to large amount of 0 and 1 in the algorithm which requires rational adjustment. On that account, the speed of particle flight can be affected by the valuing probability of particle. The function of sigmoid is shown in Eq. (1-1) and (1-2).

$$\begin{cases} X_{id}^{k+1} = 1 & \text{randn}() < \text{sigmoid}(V_{id}^{k+1}) \\ X_{id}^{k+1} = 0 & \text{randn}() > \text{sigmoid}(V_{id}^{k+1}) \end{cases} \quad (1-1)$$

$$\text{sigmoid}(V_{id}^{k+1}) = \begin{cases} 0.98 & V_{id}^{t+1} > 4 \\ \frac{1}{1+e^{-V_{id}^{t+1}}} & -4 \leq V_{id}^{t+1} \leq 4 \\ -0.98 & V_{id}^{t+1} < -4 \end{cases} \quad (1-2)$$

From the analysis of above equation, when particle flight speed presents an increasing trend, the sigmoid function value infinitely approaches to 1 but can never exceed 1, thus its value range is set as [0,1]. In Eq. (1-1), the location of particles is reset after comparing and analyzing the random number randn() and sigmoid function value. The corresponding kinematic velocity has top and bottom limit, so as to ensure stable and effective operation.

2.2 Improvement strategies of BPSO algorithm

We recognize that traditional algorithm features high stability and good convergence during long-term practice, yet, traditional BPSO algorithm suffers obvious defects after analyzing the specific operation, e.g., it is easy to fall into local optimum, failing to achieve the convergence of globally optimal solution. Therefore, a new operation method is proposed to improve the algorithm and better achieve algorithm target. Specifically, there are two improvement strategies.

The first is the learning factor. In Eq. (1-3), c_1 presents self-learning ability. By absorbing and analyzing the function of other factors, the factor can retrieve the optimal particle and quicken the speed at which other particles approach to it. However, it can weaken the ability of particles to seek for optimization when the factor value increases. c_2 represents the sum of learning ability of all particles, i.e. the social learning ability. It promotes the improvement of efficiency at which particles approach to globally optimal particles and will be interfered by locally optimal solution when the value increases^[3]. Eq. (1-3) is set based on the two accelerated factors, so as to form the compression factor.

$$\varphi = \frac{2}{\left| 2 - (c_1 + c_2) - \sqrt{(c_1 + c_2)^2 - 4(c_1 + c_2)} \right|} \quad (1-3)$$

The second is the inertia weight. Inertia weight in operation is represented by factor ω . Value change will impact the specific searching function. Value increase means that particles are equipped with self-recognition function, thus the negative effect brought by locally optimal solution can be

excluded. With small value, the convergence behavior of function can be completed quickly [4]. In practice, the function itself can achieve global searching in the initial stage of iteration, but will require to accelerate the convergence speed in the last stage. In the paper, the factor ω is improved in term of function, thus the linear size can be adjusted in order, so as to get the Eq. (1-4).

$$\omega = \omega_{\max} - \frac{T(\omega_{\max} - \omega_{\min})}{T_{\max}} \tag{1-4}$$

Where, ω_{\max} and ω_{\min} represent the maximum and minimum value of ω , respectively, and the space function valuing range is [0.4,1]; T represents the number of iterations, and T_{\max} represents the maximum iterations.

Iteration equation after improvement is expressed as,

$$\left\{ \begin{array}{l} V_{id}^{k+1} = \varphi \left[\omega V_{id}^k + c_1 \xi (P_{id}^k - x_{id}^k) + c_2 \eta (P_{gd}^k - x_{id}^k) \right] \\ X_{id}^{k+1} = X_{id}^k + V_{id}^{k+1} \\ \varphi = \frac{2}{\left| 2 - (c_1 + c_2) - \sqrt{(c_1 + c_2)^2 - 4(c_1 + c_2)} \right|} \\ \omega = \omega_{\max} - \frac{T(\omega_{\max} - \omega_{\min})}{T_{\max}} \end{array} \right. \tag{1-5}$$

2.3 Comparison between IBPSO and standard BPSO

After comparing the advantages and disadvantages of different algorithms, a judgement criterion with practical value is proposed in the paper, which is the optimal fitness value. The smaller the value, the better the function performance. Based on the simulation contrast of two expressions of Benchmark functions, we obtain the iteration curve of IBPSO and PSO. Table 1 summarizes the two expressions of Benchmark function.

Table 1 Benchmark Function Expression and Valuing Range

Function name	Expression	Valuing range	Dimension
Ackley	$20 + e - 20e^{-0.2 \sqrt{\frac{1}{n} \sum_{i=1}^n x_i}} - \frac{1}{20} \sum_{i=1}^n \cos(2\pi x_i)$	[-200,200]	50
Griewank	$\frac{1}{4000} \sum_{i=1}^n x_i^2 - \prod_{i=1}^n \cos(x_i / \sqrt{i}) + 1$	[-200,200]	50

After analyzing the abovementioned function expressions, we implement the N simulation experiment. The initial value of parameter is set as: the population number is 40, the value of other parameters is $c_1 = c_2 = 2$, $\omega_{\max} = 0.9$, $\omega_{\min} = 0.4$, and the maximum iteration number is 500. Fig. 1 and 2 below show the specific simulation contrast result.

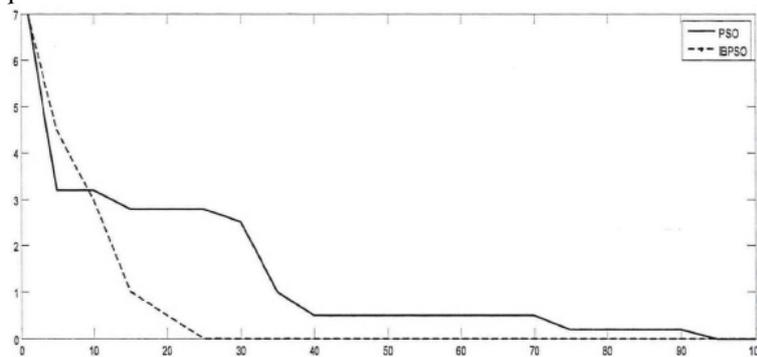


Figure 1 Ackley Function Simulation

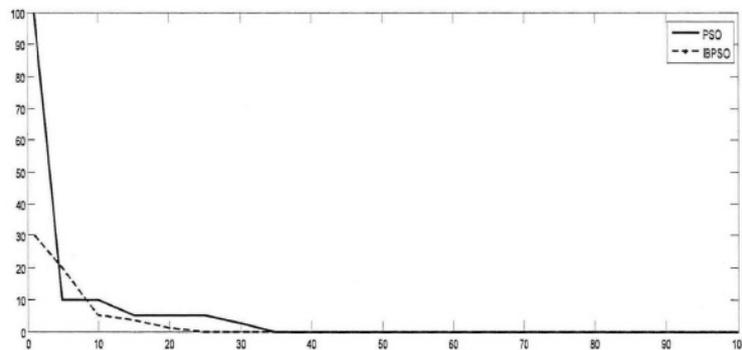


Figure 2 Griewank Function Simulation

From the two figures, Ackley function is a unimodal function where the globally minimum solution is 0. In the last stage of simulation, the expected goal of optimal speed convergence is achieved by IBPSO searching. By contrast, Griewank function is a multimodal function where 0 represents the globally optimal solution. It exhibits a good evading effect on the locally optimal disturbance.

After further analyzing the simulation contrast result, it is found that Benchmark function can use IBPSO algorithm to gain the mean value of optimal fitness function. The value is better than that got by PSO algorithm, showing IBPSO algorithm presents a better performance.

Actually, any research could suffer information distortion and obvious mismatch. BPSO can exhibit a better performance with improved fault tolerance. In the following part, we will conduct simulation contrast experiment on the fault tolerance, with results summarized in Fig. 3.

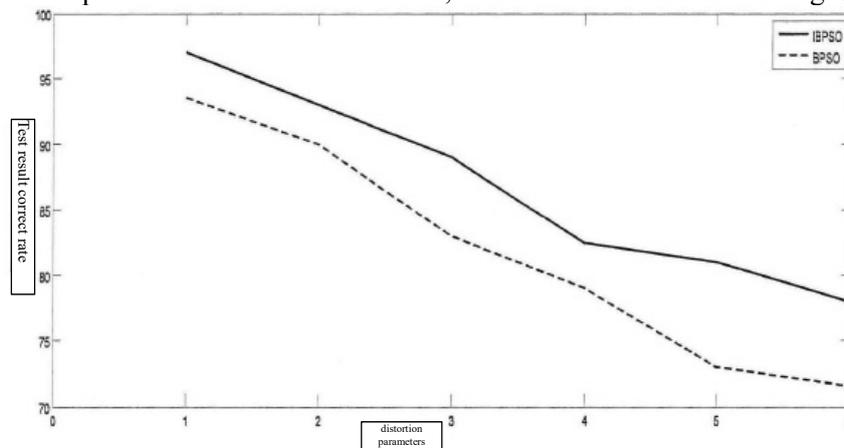


Figure 3 Precision Comparison of Test Result between IBPSO and BPSO

From Fig. 3, IBPSO exhibits a higher precision than BPSO no matter what the distortion is, thus it is concluded that the former is more suitable in treating distorted information compared with the latter. Based on the analysis, we will apply IBPSO in practical fault location in DG power distribution network and meanwhile analyze as well as summarize its practical value.

3. Function Construction of IBPSO-based Fault Location in Power Distribution Network Adopting DG

3.1 Coding mode

After confirming relevant information source based on research process and result, we think that the behavioral pattern is actually a monitoring process of FTU fault overcurrent information. By uploading monitoring information to SCADA center, the fault location information can be better stored. Based on the analysis on the FTU monitoring result, the current value of circuit is different from normally operating parameter setting value. In order to confirm the circuit fault, coding can be

adopted to analyze switch function and confirm the fault information, $I_j=1$ means normal situation and $I_j=0$ means normal operation. From traditional power distribution network, the method can well solve the coding issue. However, the addition of DG treatment will cause obvious change in system structure and stimulate the adjustment of current direction. On that account, originally defined coding method cannot suitable for system demand. In the paper, we redefine the coding mode to achieve the optimization of I_j value and implement the fault location of DG network.

One obvious issue in different topological structures of power distribution network is the circuit positive direction. For traditional system, there is only one positive direction, following which distribution transformer directs to feeder. However, DG power distribution network adopts multisource power supply mode, thus it is impossible to immediately confirm the accurate positive direction. For example, if there are 4 feeder sections between switch j and DG, yet there are 5 feeder sections between switch j and main source, the setting way should be: the positive direction is from top half section to bottom half section and the top half section is inevitably in the DG section. After analyzing the definition, it is found that the switching node only has one standard positive direction and the positive direction is of significance only for the switching node^[5].

After defining the positive direction of various switching nodes, it is allowed to conduct coding treatment. If the overcurrent direction is consistent with the positive direction, then $I_j=1$. If the results are completely opposite, the overcurrent information shall be set as $I_j=0$. Then the novel coding is obtained which can be applied in DG system and assist the fault location in power distribution network. It can be seen that the coding mode can be obviously affected by direction. From abovementioned analysis, after introducing “-1” into system function, the topological structure changes. By monitoring the overcurrent information of switching nodes, we confirm that the flow direction is totally opposite with the positive direction, then “-1” should be adopted to rationally explain the specific coding mode of DG power distribution network. All feeder sections in the system need fitness function for formulating corresponding codes. If the section exhibits stable change, 1 represents fault and 0 represents normal operation. Table 2 lists specific fault information.

Table 2 Fault Information Uploaded by FTU in DG Power Distribution Network

Status	Value	Remarks
I_j	1	Fault information in positive direction is monitored
	-1	Fault information in negative direction is monitored
	0	No fault information is monitored

Then we will empirically explain the coding mode. In Fig. 4, all switching nodes are equipped with FTU. The positive direction and relevant values are confirmed according to new coding mode.

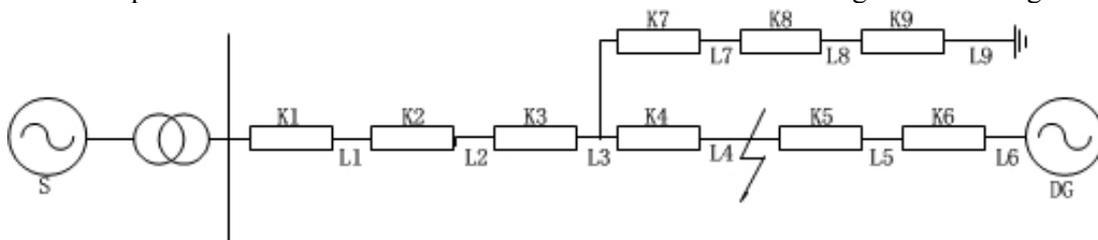


Figure 4 DG Power Distribution Network Model

After the positive direction of various switching nodes in Fig. 4 is confirmed, the specific coding mode can be confirmed accordingly. Based on comparison, K1-K3 are closer to main power source S, which achieves a better effect compared with DG. Therefore, it is reasonable to use sectional power system structure. The top half section can adopt S and the bottom half section can adopt DG. At this point, we think that K4-K6 are closer to S, thus the top half section uses DG and bottom half section focuses on S. The distance from switching node K7-K8 to top half section and bottom half section is similar, thus the positive direction can be confirmed based on operation need. From Fig. 4, if L4 sees

fault, the positive direction of switch K1-K3 can be defined to S and the DG in bottom half section represents the directional direction, which is in agreement with the hypothesis before. At this time FTU upload the data 1. In the same way, for K4-K6, the upload data is “-1”. K7-K9 belong to branch and suffer no fault in subsequent association section, thus the upload data remain 0. In short, after FTU treatment, the data set of various switching nodes in SCADA data center is [1,1,1,1,-1,-1,0,0,0].

3.2 Construction of switch function

In traditional power distribution network system, the basis of construction of switch function is 0 and 1. After the completion of the construction, there is no need to consider the direction of fault current, yet, for fault detection in DG power distribution network, it is necessary to confirm the current direction. However, the overcurrent information of switching node is not complete or regular. Therefore, it is requested to integrate information flow in order to locate fault and meanwhile confirm the network topology section by monitoring switching node.

To sum up, according to the analytical result of the switch function construction and the system function of traditional power distribution network, we hold that switch function cannot achieve the fault location of DG system, and novel switch function is needed to finish specific management on current direction and reflect the actual situation so as to confirm the fault location. After improving original switch function, we get Eq. (2-1) and (2-2), which can be applied in the switch function of DG power distribution network.

$$S_j^*(x) = L_1 + L_2 + \dots + L_j (L_j \in M) \tag{2-1}$$

$$I_j^*(x) = k_{s1} (1 - S_1^*(j)) \cdot S_2^*(j) - k_{s2} (1 - S_3^*(j)) \cdot S_4^*(j) \tag{2-2}$$

Parameter description:

“+” represents operation;

L represents the representative value of operation in feeder section;

M is the downstream association sum of switching nodes;

k_{s1} and k_{s2} stand for whether the power coefficient is connected in top half section and bottom half section, respectively, and 1 for yet;

$S_1^*(j)$ is the distance of j from S feeder in top half section as well as the operation results;

$S_3^*(j)$ is the distance of j from DG feeder in bottom half section as well as the operation results;

$S_2^*(j)$ and $S_4^*(j)$ are the status of all feeders in upper and bottom half section and also include operation results.

Table 3 summarizes the corresponding switching coefficient selection results.

Table 3 Feeder Association Diagram of Various Switching nodes

	$S_1^*(j)$	$S_2^*(j)$	$S_3^*(j)$	$S_4^*(j)$
K1	/	L1,L2,L3,L4,L5,L6, L7,L8,L9	L1,L2,L3,L4,L5,L6	/
K2	L1	L2,L3,L4,L5,L6,L7, L8,L9	L2,L3,L4,L5,L6	L1
K3	L1,L2	L3,L4,L5,L6,L7,L8, L9	L3,L4,L5,L6	L1,L2
K4	L1,L2,L3	L4,L5,L6	L4,L5,L6	L1,L2,L3,L7,L8,L9
K5	L1,L2,L3,L4	L5,L6	L5,L6	L1,L2,L3,L4, L7,L8,L9
K6	L1,L2,L3,L4,L5	L6	L6	L1,L2,L3,L4,L5, L7,L8,L9
K7	L1, L2, L3 - S ⁺ L3, L4, L5, L6 - DG ⁺	L8,L9	/	L1,L2,L3,L4,L5,L6
K8	L1, L2, L3 L7 - S ⁺ L3, L4, L5, L6, L7 - DG ⁺	L8,L9	/	L1,L2,L3,L4,L5,L6, L7
K9	L1, L2, L3, L7, L8 - S ⁺ L3, L4, L5, L6, L7, L8 - DG ⁺	L9	/	L1,L2,L3,L4,L5,L6, L7,L8

According to Table 3, each switching node will form a joint with feeders at different directions in up and bottom half section and the final results are obtained by calculating. From Fig. 11, S and DG are connected in system in succession, with the results of $k_{s1}=1$ and $k_{s2}=1$. The effect sketch of specific feeder line section shows that fault in L6 can be marked by 1. 0 stands for no fault. After comprehensively analyzing Eq. (2-1) and Eq. (2-2), the function values of switching nodes are organized as follows,

$$I1 = (1-0) * (0+0+0+1+0+0+0+0) - [1-(0+0+0+1+0+0)] * 0 = 1;$$

$$I2 = (1-0) * (0+0+1+0+0+0+0+0) - [1-(0+0+1+0+0)] * 0 = 1;$$

$$I3 = [1-(0+0)] * (0+1+0+0+0+0+0) - [1-(0+1+0+0)] * (0+0) = 1;$$

$$I4 = [1-(0+0+0)] * (1+0+0) - [1-(1+0+0)] * (0+0+0+0+0+0) = 1;$$

$$I5 = [1-(0+0+0+1)] * (0+0) - [1-((0+0))] * (0+0+0+1+0+0+0) = -1;$$

$$I6 = [1-(0+0+0+1+0)] * 0 - (1-0) * (0+0+0+1+0+0+0+0) = -1;$$

$$I7 = [1-(0+0+0)+1-(0+I+0+0)] * (0+0+0) - 0 * (1-0) * (0+0+0+1+0+0) = 0;$$

$$I8 = [1-(0+0+0+0)+1-(0+1+0+0+0)] * (0+0) - 0 * (1-0) * (0+0+0+1+0+0+0) = 0;$$

$$I9 = [1-(0+0+0+0+0)+1-(0+1+0+0+0+0)] * 0 - 0 * (1-0) * (0+0+0+1+0+0+0+0) = 0.$$

Hence, the fault information set uploaded by FTU is [1,1,1,1,-1,-1,0,0,0]. When there is information distortion uploaded by FTU in coding mode, the overcurrent information is consistent with fault information. It can be seen that that new switch function is able to validate the feasibility of fault location in DG power distribution network and fitness function gets its rational analysis and explanation.

3.3 Construction of fitness function

For fault location in traditional power distribution network system, fitness function is needed to ensure the location precision, which is the same for DG power distribution network system. Switch function is the basis for constructing fitness function. New switch function shall rationally locate fault in DG power distribution network by constructing new fitness function.

From analysis on traditional power distribution network, the fitness function is expressed as,

$$Fit(x) = \sum_{j=1}^N |I_j(x) - I_j^*(x)| + w \sum_{j=1}^M |S_B(j)| \quad (2-3)$$

Actually, misjudgment always occurs in practical application system, that's why we add the second item in the right side of above equation. Fig. 5 is research case, which can explain feasibility of fitness function in fault judgment in DG power distribution network.

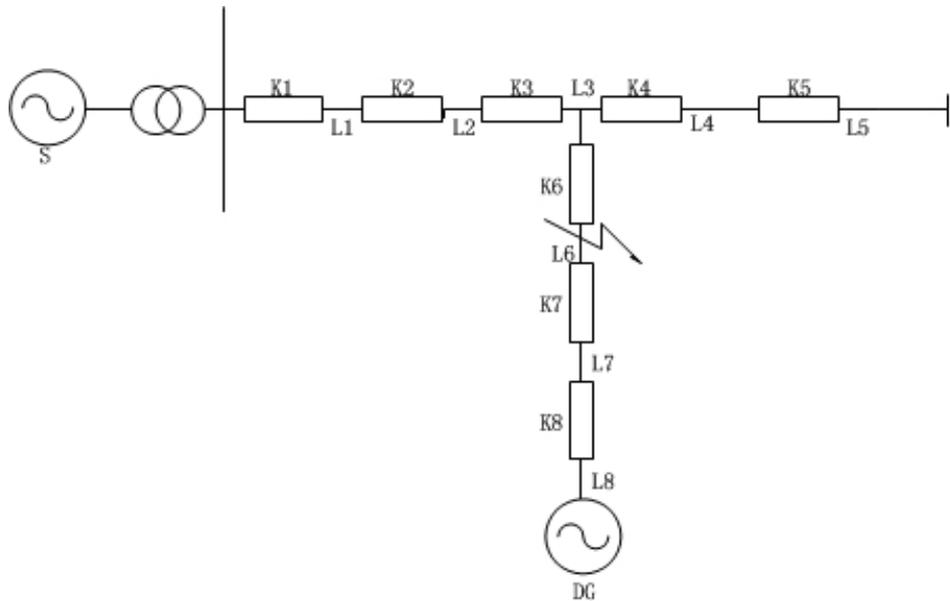


Figure 5 DG Power Distribution Network Numerical Example Model

After confirming L6 fault, it can be seen that the information uploaded in real time by FTU is marked as 1, thus corresponding function relation is

$I_j^*(x) = 1 * [1 - (0 + 0 + 0)] * (1 + 0 + 0) - 1 * [1 - (1 + 0 + 0)] * (0 + 0 + 0 + 0 + 0) = 1$. In this case, the first item in right side of equation is 0, and the second item is 0.5, which is the minimum fitness value after experiment validation and can be used to rationally confirm the fault section.

It can be seen that fitness function enjoys a good fitness in both traditional and DG power distribution network. The difference is that switch function is the basis of all functions, which should be used by corresponding fitness function to achieve different functions.

4. Application of IBPSO in Fault Location in Power Distribution Network Adopting DG

After analyzing standard BPSO, we think that iteration formula shall be optimized for achieving corresponding improvement. Based on the comparison of different power grid forms, in order to confirm specific fault location, it is necessary to use different function types, which will lead to corresponding changes. On that account, we make an in-depth analysis on the overcurrent fault information of switching node, the topological structure of power distribution network and the switch function corresponded by feeder section, etc. and draw the conclusion that fitness function is needed to complete fault location of DG system. Particle swarm algorithm is the basis of all methods. According to the coding mode in the flow chart, the iteration formula can be optimized and upgraded to locate the fault, as shown in Fig. 6.

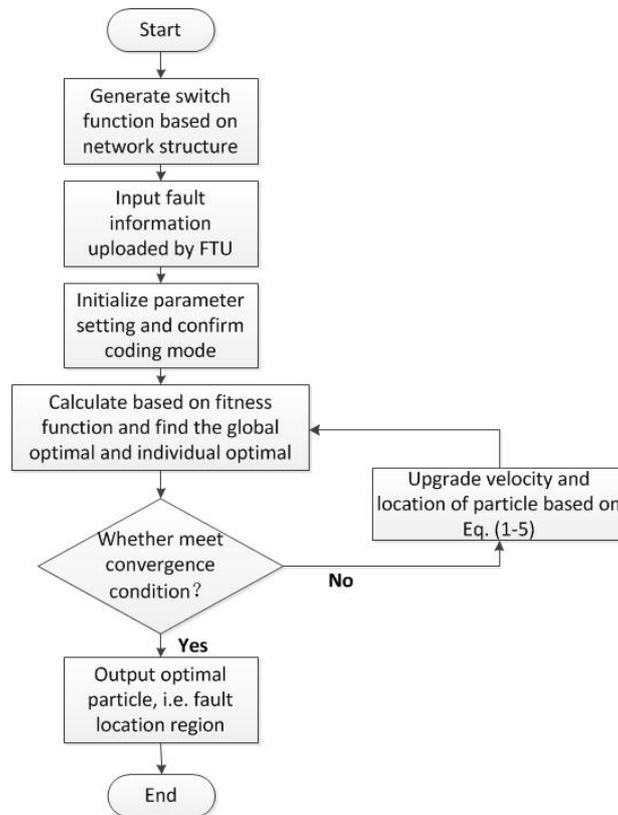


Figure 6 IBPSO-based Fault Location Flow in Power Distribution Network adopting DG

5. Simulation Numerical Example Analysis

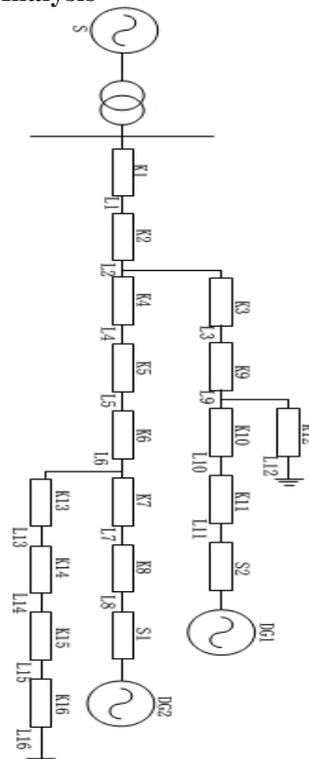


Figure 7 Fault location Simulation Model in Power Distribution Network adopting DG

In Fig. 7, K1-K16 all contain FTU switching node. In L1-L16 feeder section, two DGs can be connected in parallel to power distribution network. Then the resulting S1S2 are the specific accessing switches. Taking MATLAB as basic operation environment, simulation treatment is performed using M file in virtue of improved iterative formula and fitness function of BPSO following the flow in Fig. 6.

The simulation results are summarized in Table 4.

Table 4 Simulation Result of Fault location in Power Distribution Network adopting DG

FTU uploading information	[S1, S2]	Distortion location	Output	Fault section
[1,1,-1,-1,-1,-1,-1,1,1,-1,-1,0,0,0,0]	[1,1]	No	[000000000100000]	L11
[1,1,1,1,-1,-1,-1,0,1,-1,-1,0,0,0,0]	[1,1]	L9	[000100000000000]	L4
[1,1,1,1,-1,-1,-1,1,1,-1,-1,0,0,0,0]	[1,1]	No	[000100001000000]	L4,L9
[1,1,1,-1,-1,0,-1,-1,1,1,0,0,0,0,0]	[1,1]	L6	[001000000001000]	L3,L12
[1,1,1,1,1,1,-1,-1,0,0,0,0,1,0,0]	[1,0]	No	[000000000000100]	L14
[1,1,1,1,1,-1,-1,-1,0,0,0,1,0,0,0,0]	[1,0]	L12	[000010000000000]	L5
[1,1,1,1,1,1,1,-1,0,0,0,0,0,1,0,0]	[1,0]	No	[0010000000000100]	L3,L14
[1,1,1,1,1,1,0,-1,1,1,0,0,1,1,0,0]	[1,0]	L7	[000000000001100]	L13,L14
[1,1,0,0,0,0,0,0,-1,-1,-1,-1,0,0,0,0]	[0,1]	No	[010000000000000]	L2
[1,1,1,1,1,1,0,1,-1,-1,-1,-1,0,0,0,0]	[0,1]	L8	[000001000000000]	L6
[1,1,1,1,1,1,0,0,1,1,-1,-1,0,1,1,0]	[0,1]	No	[000000001000010]	L10,L15
[1,1,1,0,0,0,0,0,1,1,-1,-1,1,1,0,0]	[0,1]	L14	[0010000000001000]	L3,L13

Based on above simulation result, IBPSO algorithm can achieve a better fault location in DG power distribution network. FTU is used to upload the information distortion situation. The BPSO sees improved fault tolerance and will not be obviously affected by interference issue, thus the fault location effect is better. According to preceding analysis, IBPSO holds a better fault tolerance.

6. Conclusion

The standard BPSO is improved by introducing compression factor and LDIW. The IBPSO enjoys improved convergence and fault tolerance. Meanwhile, after applying the new algorithm into new field, the coding mode is improved and optimized in DG power distribution network. Simulation experiment is adopted to rationally validate the feasibility of new algorithm and gains the satisfactory results, which provides better technical space for system management of power distribution network as well as achieves the popularization and promotion of DG power distribution network in modern society.

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