Reactive power optimization and fault analysis based on intelligent distribution network simulation platform

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Keywords: intelligent distribution network; simulation and modeling; reactive power optimization; fault analysis

Abstract: Intelligent distribution network is one of the key technologies and the important part of smart grid. It has great significance to the high-quality electric energy and the promotion of new energy revolution which can promote environmental protection and sustainable development. At present, our country's smart distribution network is still in its initial stage which is relatively weak. It cannot solve the problem of a large number of renewable energy accesses to the power grid and achieve the optimal operation of distribution network and itself healing control. With the gradual deepening of the construction of smart distribution network, the future power grid will be more complex, and its operation and control is bound to be more highly dependent on digital simulation tools. At first, the three aspects of the distribution network simulation platform is analyzed in this paper. Secondly, the model and algorithm of the function module of the simulation platform are analyzed in the two parts of the reactive power optimization and fault analysis. Reactive power optimization part of the column writes the objective function, equality and inequality constraints. The function of reactive power optimization is realized by using particle swarm optimization algorithm. Fault analysis section describes the module data relations, three-phase short-circuit fault and asymmetric fault processing flow. Finally, the line model is built in the simulation platform, which verifies the correctness of the simulation platform.

1. Introduction

The intelligent distribution network is an important part of the smart grid field, with higher power supply reliability. It is related to whether the smart grid of China's future power grid can be successfully realized, and has received extensive attention in recent years. The performance of a large number of distributed power supply equipment, the access of new hybrid electric vehicles, a large number of power distribution main stations, terminal equipment and user equipment connected to the grid, bring challenges to the operation and control of the distribution network [1-2]. The research and development of the intelligent distribution network simulation research platform is of great significance for ensuring the safe and stable operation of the power system. It not only provides strong technical support for the intelligent distribution network research, but also enables the dispatching operators to have the foresight of predicting the future changes of the system. Make decisions and implement controls in advance.

The world's demand for electricity is at a critical turning point, and research on smart distribution networks in the future is of great significance to economic and social development [3-5]. At present, some research institutes have developed a variety of simulation platforms. The technical requirements, basic functions, main design ideas, local automation functions, self-healing, local automation functions, simulation and modeling for rapid simulation and modeling of power distribution systems [6-8] . The tool set has been briefly introduced, emphasizing the role of DFSM in the distributed intelligent architecture of smart distribution networks. The advantage of this method compared to the dynamic model is that it does not require an actual point of failure and saves investment. This paper first analyzes the functional architecture of the distribution network simulation platform from three aspects. Then, through the two parts of reactive power optimization and fault analysis, the model and algorithm of the functional module of the simulation platform are analyzed. The reactive power optimization part lists the objective function and equation. Inequality constraints and the particle swarm optimization algorithm are used to realize the function of reactive power optimization. The fault analysis part introduces the module data relationship, three-phase short-circuit fault and asymmetric fault processing flow. Finally, a circuit model is built in the simulation platform. Simulation verification was performed.

2. Simulation Model and Algorithm

The simulation function of intelligent distribution network simulation research platform mainly includes power flow calculation, reactive power optimization, self-healing simulation, fault analysis, network reconstruction and state estimation. The main focus of this paper is to analyze reactive power optimization and fault analysis.

2.1 Reactive power optimization model

The reactive power optimization mathematical model can be described as:

$$\begin{cases} \min \ \ F = f(u,x) \\ s.t. \ \ g(u,x)=0 \\ \qquad h(u,x)\le 0 \end{cases} \tag{1}$$

In the formula, u is an adjustable control variable, such as the number of switching nodes of the generator node voltage, the adjustable ratio transformer tap and the reactive compensation capacitor; x is the state variable, including all loads except the generator node The voltage of the node and the reactive power of the PV node generator [9-11].

The objective functions of reactive power optimization:

$$F = P_{loss} + \lambda_1 \sum_{i\in N_{PQ}} \left(\frac{V_i - V_{i\lim}}{V_{i\max} - V_{i\min}} \right)^2 + \lambda_2 \sum_{i\in N_G} \left(\frac{Q_i - Q_{i\lim}}{Q_{i\max} - Q_{i\min}} \right)^2 \tag{2}$$

In the formula, P_{loss} is the system active loss obtained in the power flow calculation. The calculation formula is as follows:

$$P_{loss} = \sum_{i=1}^{N}\sum_{j=1}^{N} G_{ij}[V_i^2 + V_j^2 - 2V_iV_j\cos\delta_{ij}] \tag{3}$$

V_{ilim} and Q_{ilim} are the limits of the voltage and reactive power of node i, respectively, as follows:

$$V_{i\lim} = \begin{cases} V_{i\min} & V_i < V_{i\min} \\ 0 & V_{i\min} < V_i < V_{i\max} \\ V_{i\max} & V_i > V_{i\max} \end{cases}$$

$$Q_{i\lim} = \begin{cases} Q_{i\min} & Q_i < Q_{i\min} \\ 0 & Q_{i\min} < Q_i < Q_{i\max} \\ Q_{i\max} & Q_i > Q_{i\max} \end{cases} \tag{4}$$

In the formula,

$V_{i\max}$, $V_{i\min}$ - Upper and lower limits of the load node voltage.

$Q_{i\max}$, $Q_{i\min}$ - The upper and lower limits of the generator's reactive output.

λ_1 - The load node voltage exceeds the penalty factor.

λ_2 - The generator reactive power exceeds the penalty coefficient.

2.2 Distribution network failure analysis

For the conventional fault calculation method, for the treatment of network topology and impedance parameter changes to the network, the branch addition method is mostly used to correct the network node impedance matrix. The disadvantage of this calculation method is that in the simulation method of network operation, when the power system with mutual inductance coupling line is encountered, the calculation process becomes quite cumbersome, the flexibility is poor, the calculation amount is large, and the large-scale power system is simulated to perform multiple operations. At the time of each network operation, the network mathematical model needs to be re-modified, so the above problem becomes more prominent [12-15]. The simulation analysis platform failure analysis module of this paper can effectively solve such problems.

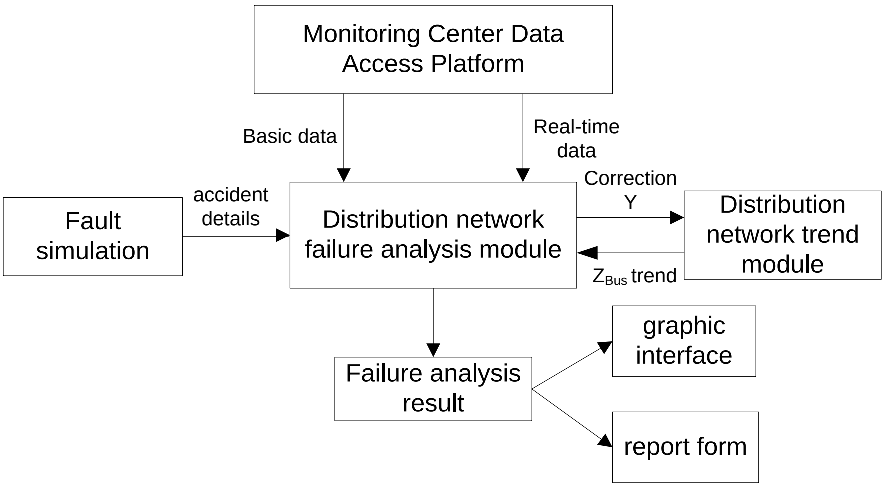

Figure 1. Data relationship of the distribution network fault analysis module

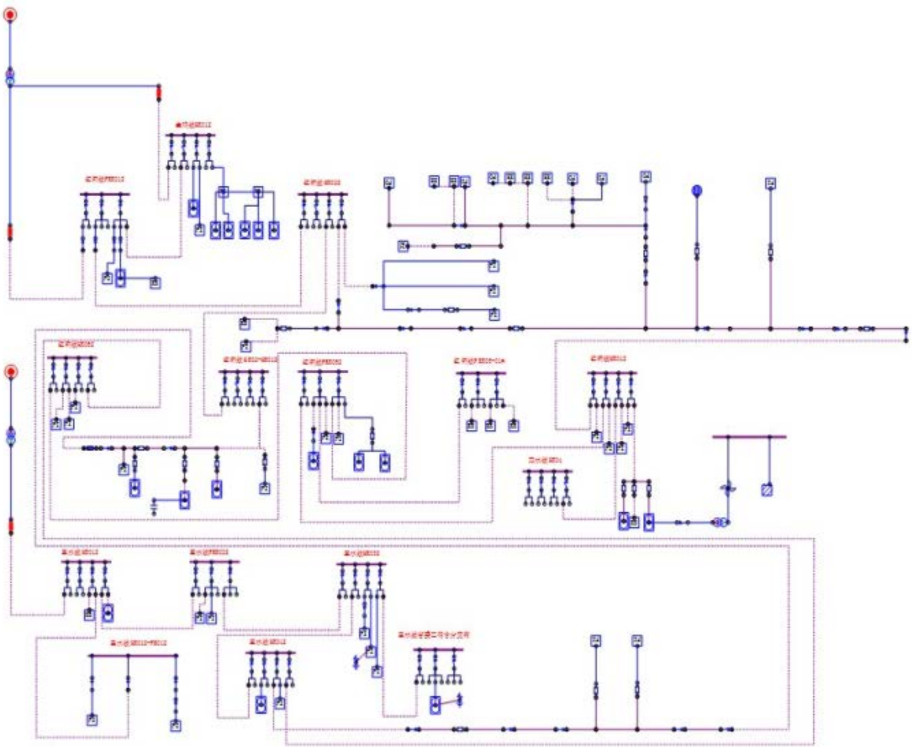

Figure 2. Line model diagram

3. Case Application Analysis

The primary wiring diagram of the Honggang line in Jinan City was selected as an example to demonstrate the correctness and effectiveness of the intelligent distribution network simulation research platform. The line model diagram is shown in Figure 2. The number of wiring diagram devices: 2 power points, 24 switches, 63 loads, 2 tie switches.

3.1 Reactive power optimization analysis results

After the multi-time reactive power optimization is completed, the system network loss in each period of the reactive power optimization process, the capacitor compensation capacity in each period, and the position of the transformer taps in each period can be obtained.

Reactive power optimization requires load curve support. The main result of reactive power optimization is to obtain the capacitor capacity and network loss corresponding to each time point according to the time point in the load curve. The system network loss of each capacitor during the simulation period is shown in Table I.

TABLE I. System network loss of each simulation period of capacitor

Simulation period	System network loss (kW)
01:00	6.466
02:00	7.927
03:00	8.052
04:00	7.4
05:00	7.189
06:00	8.502
07:00	9.2
08:00	10.136
09:00	12.228
10:00	13.637
11:00	18.334
12:00	15:125

The reactive power optimization problem is a multivariable and multi-constrained hybrid nonlinear programming problem. Its control variables have both continuous variables (generator voltage and reactive output) and discrete variables (loaded regulator tap positions). The compensation capacitors and the number of switching reactors of the reactors make the reactive power optimization process very complicated. The reactive power optimization module solves a series of problems that cannot be adapted to real-time control requirements and “dimensional disasters” due to the fact that the constraints are beyond the limits.

3.2 Short circuit fault analysis result

The fault currents and fault voltages at different equipment connection points on the line are shown in Table II.

TABLE II. Fault current and fault voltage of the connection point

Junction	Phase A voltage /kV	Phase B voltage /kV	Phase C voltage /kV
1067	66.335	66.335	66.34
1110	6.059	6.059	6.059
1111	6.059	6.059	6.059
1109	6.059	6.059	6.059
1159	6.059	6.059	6.059
1130	6.059	6.059	6.059
1131	6.059	6.059	6.059
1132	6.058	6.058	6.058
1133	6.058	6.058	6.058
1134	6.058	6.058	6.058
1135	6.058	6.058	6.058
1136	6.058	6.058	6.058
1137	6.058	6.058	6.058
1155	6.058	6.058	6.058

When an A-phase short-circuit fault occurs, the fault current and voltage data of different equipment connection points on the line are shown in Table II. Phase A is short-circuited by single-phase grounding and its voltage is 0; b and c phases have no ground short-circuit fault, and the phase voltages are about 9.8kV. After the single-phase grounding short-circuit fault occurs in phase A, the fault current increases significantly compared with the phase current before the fault. It can be seen from the results in Table II that the simulation model built in this paper can simulate the short circuit fault of the distribution network.

According to the above simulation case, the fault analysis function of the platform can detect, analyze, analyze and record faults of various symmetric faults and asymmetrical faults, the problem that the calculation process of the system is cumbersome, the flexibility is poor, and the calculation amount is large due to the mutual inductance coupling line is effectively solved.

4. Conclusion

This paper studies the key technologies and implementation methods of intelligent distribution network simulation, synthesizes the latest achievements in this field, and uses systematic analysis, mathematical modeling, and field data analysis to conduct systematic research. This paper first analyzes the functional architecture of the distribution network simulation platform from three aspects. Then it analyzes the model and algorithm of the functional module of the simulation platform through reactive power optimization and fault analysis, and uses the particle swarm optimization algorithm to realize the function of reactive power optimization. The analysis part introduces the module data relationship, three-phase short-circuit fault and asymmetric fault processing flow. Finally, the simulation is verified based on a certain line model built in the simulation platform. The simulation results prove its effectiveness.

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