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Research on Distribution Network Reliability and Power Supply Soft Self-healing

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Abstract: The reliability of distribution network is an important index to ensure high-quality power supply. In this paper, the FMEA table is established based on the traditional power supply mode consequence analysis method, and the network topology after power supply isolation is determined by querying the table according to the power supply information. Then, the control mode of VSC is adjusted according to the VSC control strategy under different power supply conditions. Finally, through network reconfiguration and island operation, the continuous spatiotemporal power grid topology power supply restoration optimization model is established. On this basis, this paper combines sequential Monte Carlo method to evaluate the reliability of continuous spatiotemporal power grid topology, and illustrates the reliability evaluation difference caused by the difference of distribution network topology information.

1. Introduction

Power supply self-healing of distribution network is a fast automatic way of accident recovery, which requires the input of automatic monitoring and control equipment. On the basis of existing automation equipment, using accurate continuous space-time topology information of distribution network to realize "soft self-healing" as far as possible can reduce the cost of automatic restoration of power supply.

2. Reliability evaluation model

With the continuous development of DC distribution technology and the large-scale access of DC equipment such as distributed generation and electric vehicles, continuous space-time power grid topology has become the development trend of distribution network in the future. Reliability is the first factor to be considered in power grid construction. It is of great significance to evaluate the reliability of continuous space-time power grid topology. The control mode of voltage source converter in continuous space-time power network topology can be flexibly adjusted, so it can restore power supply by adjusting VSC control mode, network reconfiguration and isolated island operation of distributed generation after power supply. In order to accurately evaluate the reliability of continuous space-time power grid topology, the impact of the above recovery methods on reliability needs to be fully considered. Most of the traditional reliability evaluation methods only consider the impact of restoration through smart contact switch switching after power supply.

The existing reliability evaluation methods for continuous space-time power grid topology mainly consider the impact on reliability by adjusting VSC control mode after power supply. We establish FMEA table based on traditional power supply mode consequence analysis method, According to the power supply information, query the table to determine the network topology after power supply isolation; then adjust the control mode of VSC according to the VSC control strategy under different power supply conditions; finally, through the continuous space-time power grid topology power supply recovery optimization model of network reconstruction and island operation, on this basis, combined with sequential Monte Carlo method, the reliability of continuous space-time power grid topology is evaluated.

2.1 Continuous space-time and cognitive model of distribution network

The continuous space-time of distribution network is the information space-time of human cognition of distribution network business activities. It is described by four-dimensional space-time and recorded as PDO (power grid operation object):

$$\mathrm{PDO} = (\mathrm{X}, \mathrm{Y}, \mathrm{Z}, \mathrm{t}) \tag{1}$$

Where x, y, Z are spatial position coordinates and t is time coordinates. Each four-dimensional space-time point (x, y, Z, t) corresponds to the three-dimensional space of a specific time t.

Each professional link of distribution business is distributed in different time and space regions in PDO. These time and space regions are "professional time and space", which are "planning time and space", "construction time and space", "operator time and space", "marketing time and space", "distribution network time and space" and "regulation time and space". The distribution business objects in each "professional time and space" are in "future", "current situation" "History" has three different temporal and spatial states.

In PDO, the "power grid information" precedes the "power grid entity": the physical power grid starts from the planning concept of "imagination", appears on "paper" and becomes the planning and design scheme in the "future" tense, then "implemented" to "ground" through engineering construction and put into operation to become the "current" entity power grid, and finally decommissioned and dismantled gradually to become the "history" existing in the data world Temporal power grid becomes a complete spatio-temporal evolution process of distribution network business object.

If "grid cognitive model" C_ PG (cognitive power grid) describes this spatiotemporal evolution process, which includes four basic cognitive dimensions. They are power grid equipment attribute cognitive dimension a C, network topology connection cognitive dimension T C, network load and operation state cognitive dimension P C, and network load, equipment location and geographical support cognitive dimension g C. The contents of each dimension include relevant information, knowledge and theory, which are time functions in PDO. Recorded as:

$$\mathrm{C\_PG(t)} = \{\mathrm{A\,c\,(t)}, \mathrm{T\,c\,(t)}, \mathrm{P\,c\,(t)}, \mathrm{G\,c\,(t)}\} \tag{2}$$

Where t is the real world time, which contains four basic information dimensions related to the distribution network:

A C (T) is the dimension of equipment attribute information and knowledge;

T C (T) is the network topology information and knowledge dimension;

P C (T) is the information and knowledge dimension of network load and operation status;

G C (T) refers to the auxiliary attribute information and knowledge of power grid equipment and load, as well as its corresponding geographic geometric information and knowledge dimension (including engineering geometric information).

Objective function

The main objective of the distribution network reliability evaluation model based on continuous space-time network topology is to restore the power loss load as much as possible after the power supply occurs. In addition, the network loss in the restored operation state also needs to be considered. Therefore, the sub objective F of the model is to maximize the load recovery during power supply:

$$\max f_1 = \sum_{i \in N} \sum_{t=t_{start}}^{t_{end}} \lambda_i P_{i,t}^{LOAD} \tag{3}$$

Where: N is the collection of load points in the distribution network; t_{start} is the start time of power supply; t_{end} is the end time of power supply; λ_i is the recovery factor of load point i, λ= 1 means to restore power supply, λ=0 means that the power supply will not be restored; $P_{i,t}^{LOAD}$ is the active power of the load on node i in period T.

Sub objective f_2 in order to minimize the network loss in the restored operation state, different from the traditional AC distribution network, the topology network loss power of continuous space-time power grid also needs to take into account the loss power of converter station and DC network:

$$\min f_2 = \sum_{t=t_{start}}^{t_{end}} \left(\sum_{ij=B_{AC}} I_{AC}^2 + \sum_{mn=B_{DC}} I_{DC}^2 + \sum_{pq \in B_{VSC}} (1 - \eta_{pq,t}) P_{VSC,pq,t} \right) \tag{4}$$

Where:

$$\eta_{pq,t} = \frac{u_{pq,t}}{0.004+1.002u_{pq,t}+0.018u_{pq,t}^2}, \eta_{pq,t} = P_{VSC,pq,t}/P_{VSC,pq}^N. \tag{5}$$

Where: B_{AC}, B_{DC} and B_{VSC} is the collection of AC branch, DC branch and converter station branch in distribution network; $I_{AC,ij}$ is the current of AC branch ij and DC branch Mn in period T; R_{ij} andR_{mn} is the resistance of branch ij and mn: $P_{VSC,pq,t}$ is the active power transmitted by the converter station branch PQ in period T; $\eta_{pq,t}$ and $u_{pq,t}$ are respectively the commutation efficiency and load rate of the branch PQ of the converter station in period T.

The set weight method is used to synthesize two sub objectives:

$$\min F = -\lambda_1 f_1 + \lambda_2 f_2. \tag{6}$$

Constraint condition

Radial operating constraints.

In the continuous space-time power grid topology, the DC network does not need to meet the constraint, but the AC network only needs to meet the constraint:

$$\begin{gathered}\beta_{ij}+\beta_{ji}=a_{ij}, ij\in B_{AC}\\ \sum_{IJ\in B_{AC}}\beta_{ij}=1,\forall i\in N_{AC}/N_{AC,slack}\\ \sum_{IJ\in B_{AC}}\beta_{ij}=0,\forall i\in N_{AC,slack}\\ a_{ij},\beta_{ij},\beta_{ij}\in\{0,1\}\end{gathered}\tag{7}$$

AC network power flow constraints.

When the AC branch is disconnected, there is no current and power transmission, that is, when $a_{AC,ij}=0$, the power and current of the corresponding branch are 0, and the branch does not need power flow calculation. Therefore, the large M method is used to establish AC network power flow constraints:

$$\begin{gathered}\sum_{ik\in B_{AC}}P_{AC,ik,t}=\sum_{ij\in B_{AC}}\left(P_{AC,ji,t}-R_{ji}I_{AC,ji,t}^2\right)+P_{AC,i,t}\\ \sum_{ik\in B_{AC}}Q_{AC,ik,t}=\sum_{ij\in B_{AC}}\left(Q_{AC,ji,t}-X_{ji}I_{AC,ji,t}^2\right)+Q_{AC,i,t}\\ P_{AC,i,t}=P_{AC,i,t}^{P}+P_{AC,i,t}^{W}-P_{AC,i,t}^{L},\ \ Q_{AC,i,t}=Q_{AC,i,t}^{P}+Q_{AC,i,t}^{W}-Q_{AC,i,t}^{L}\\ U_{AC,i,t}^2-U_{AC,j,t}^2-2\left(R_{ij}P_{AC,ji,t}+X_{ji}I_{AC,ji,t}^2\right)\geq 0\\ I_{AC,ij,t}=\frac{P_{AC,ji,t}^2+Q_{AC,ji,t}^2}{U_{AC,i,t}^2}\end{gathered}\tag{8}$$

DC network power flow constraints.

The large M method is also used to establish DC network power flow constraints:

$$\begin{gathered}\sum_{mk\in B_{DC}}P_{DC,mk,t}=\sum_{nm\in B_{DC}}\left(P_{DC,mn,t}-R_{mn}I_{DC,nm,t}^2\right)+P_{DC,mn,t}\\ P_{DC,mn,t}=P_{DC,m,t}^{P}+P_{DC,m,t}^{W}-P_{DC,m,t}^{L}\\ U_{DC,m,t}^2+U_{DC,n,t}^2-2R_{mn}P_{DC,mn,t}+R_{mn}^2I_{DC,mn,t}^2+M\left(1-a_{DC,mn,t}\right)\geq 0\\ U_{DC,m,t}^2+U_{DC,n,t}^2-2R_{mn}P_{DC,mn,t}+R_{mn}^2I_{DC,mn,t}^2-M\left(1-a_{DC,mn,t}\right)\leq 0\\ I_{DC,mn,t}=\frac{P_{DC,mn,t}^2}{U_{DC,mn,t}^2}\end{gathered}\tag{9}$$

Branch capacity constraints.

Branch capacity constraints include AC branch capacity constraints, DC branch capacity constraints and converter station branch capacity constraints:

$$\begin{gathered}-P_{AC,ij}^{max}a_{ij}\leq P_{AC,ij,t}\leq P_{AC,IJ}^{max}a_{ij}\\ -P_{DC,mn}^{max}a_{mn}\leq P_{DC,mn,t}\leq P_{DC,mn}^{max}a_{mn}\\ -P_{VSC,pq}^{max}a_{pq}\leq P_{VSC,pq,t}\leq P_{VSC,pq}^{max}a_{pq}\end{gathered}\tag{10}$$

Voltage constraints.

Node voltage constraints include AC node voltage constraints and dc node voltage constraints:

$$\begin{aligned}&\left(U_{AC,i}^{min}\right)^2 \le U_{AC,i,t}^2 \le \left(U_{AC,i}^{max}\right)^2\\&\left(U_{DC,i}^{min}\right)^2 \le U_{DC,i,t}^2 \le \left(U_{DC,i}^{max}\right)^2\end{aligned} \tag{11}$$

2.2 Convex relaxation treatment and solution of model

The quadratic term and product term in the power supply restoration optimization model are linearized, and the variables u and I are used to replace the square terms U^2 and I^2 of node voltage and branch current in the above formula.

The power supply restoration optimization model is transformed into a second-order cone programming model, which can be solved by using the existing mathematical optimization technology CPLEX.

2.3 Difference analysis between sequential Monte Carlo method and reliability evaluation

The above method is combined with sequential Monte Carlo method.

The distribution network reliability evaluation of continuous spatiotemporal network topology is carried out for current hybrid distribution network.

The influence of different recovery methods on reliability evaluation results is considered from the perspective of fault impact. For the convenience of analysis, four areas are divided. Considering that the fault may occur at any time, define "load comprehensive outage times" and "load comprehensive outage time" (respectively the average value of load outage times and outage time at each time within 24h). Since C2 fault has no impact on the network, it does not need to be analyzed.

In case of fault in zone 1 or DC circuit breaker QF2 fault, AC load 33.64 will not be affected. After fault isolation, AC power supply 1 fails, and DC loads 1 - 32 need to be powered by AC power supply 2. However, limited by power flow constraints, DC loads 1-32 can be restored to power supply in low load period, and the loads on branch lines in other periods will be cut off according to the situation, and only some DC loads can be restored to power supply.

For the fault, it is necessary to isolate the fault through the switch. When considering the method of fault recovery, the power is cut off once and the switching action is 0.5h (we think that after the circuit breaker is disconnected, the action of interconnection switch, transfer switch and disconnector can be carried out at the same time). It can be seen that when the DC circuit breaker QF2 fails, for any DC load 1-32, the fault impact analysis of zone 2. For the DC main feeder fault in zone 2, the upstream load of the fault is still restored by AC power supply 1. Through network reconstruction, the downstream load of the fault is still restored by AC power supply 1, with power failure once and switching action time of 0.5h; During calculation, after vsc2 is adjusted to udcq control, AC power supply 2 restores power supply, power failure once and switching action time 0.5h. However, if the fault DC main feeder is close to AC power supply 1 and there are many loads downstream of the fault, the load on the main feeder can be restored during the peak load period due to the restriction of power flow.

So far, we analyze a distribution network reliability evaluation model that depends on continuous spatiotemporal power network topology, and give the reliability evaluation difference caused by the difference of topology information. Once the problem is solved.

3. Model evaluation

This method fully considers the impact on reliability after continuous space-time power grid topology fault by adjusting VSC control mode, network reconfiguration and distributed generation island operation. Therefore, the calculated system reliability index is more practical and can accurately evaluate the reliability of continuous space-time power grid topology.

References

[1] Sun Yuanyuan, Zhang Wenjun, Shan Hongtao, Chen chuanjuan, Duan Chuanke. Reliability analysis of distribution network based on DBN [J]. Manufacturing automation, 2021, 43 (07): 64-67 + 86

[2] Zhang Lu, Yu Shunjiang, Wang Chen, Tang Wei, Zhang Xiaohui. Reliability evaluation of AC / DC hybrid distribution network considering VSC operation mode and fault recovery optimization [J / OL]. Power grid technology: 1-13 [2021-08-10] https://doi.org/10.13335/j.1000-3673.pst.2021.0169.

[3] Liu Liyang, Li Xin, Zhang Wentao, Wei Jun, ye Shengyong. Severity analysis and reliability evaluation of power outage perceived by distribution network users [J]. Sichuan electric power technology, 2021, 44 (03): 61-68.

[4] Zhou Dandan. Automatic judgment, estimation and control of line faults in complex dynamic networks [D]. Huazhong University of science and technology, 2019.