Research Locating and Sizing Method of Flexible Closed-loop Device Network Controller Based on Entropy Weight Ideal Solution

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***Abstract*—The application of the flexible closed-loop device can be used to solve the problems that the distribution network can't continue to run under the looped operation and improve the reliability of power supply. The location model based on the "primary screening-fine screening" mode is established by means of decoupling the locating and sizing issues in order to solve the locating and sizing NP-hard problems of the flexible closed-loop device in this paper. The model is central with power supply reliability and taking into account of the supply capacity and economic through entropy and ideal point analysis manner for comprehensive assessment program optimization. The sizing model is established based on net load and feeder capacity carrying out the life cycle management of assets concept, and three kinds of applicable sizing methods applied in different stages of development grid are studied based on the analysis of different stages of development characteristics of the grid. The scientific and engineering practicality of this model is showed through the analysis of a demonstration area.**

***Index Terms*—MV distribution network; flexible closed-loop device; primary screening-fine screening; locating and sizing**

I. INTRODUCTION

At present, the development of the global distribution network is faced with the difficulties of further improving the reliability of power supply and the large-scale acceptance of distributed energy[1]. The flexible DC technology provides the possibility to solve this problem. Building AC/DC hybrid distribution network with the help of flexible DC technology makes it better to accept distributed power supply and DC load and relieve the contradiction between high load density and high resource tension of urban power grid corridor. At the same time, dynamic reactive power support can be realized in the load center, so as to improve the security and stability level of the system and improve the power quality, which is the development direction and strategic choice of the future power system[2-3].

Most of Urban medium-voltage distribution networks in China adopt "closed-loop design and open-loop operation"[4] at present, which don't have the capacity of power flow regulation, load balance and continuous load transfer.

In order to solve the above problems, domestic and foreign scholars proposed to use the power controller of the loop network based on the backrest DC interconnection to realize the closed-loop operation and power flow control[5]. In view of improving the power supply reliability, power supply capacity and mass acceptance of distributed energy, it is necessary to upgrade urban medium voltage distribution network with the flexible closed-loop device. By installing a flexible closed-loop device at the key nodes, the power supply capacity of the distribution network can be better utilized which also improves the stability and reliability of the power network. 'Power grid construction, planning first', how to optimize the location of the flexible closed-loop device is the key to the construction of AC/DC hybrid distribution network, and that is also the problem to be solved in this paper.

II. LOCATION MODEL OF FLEXIBLE DC LOOP NETWORK CONTROLLER

A. *Objective Function*

A 10kV "primary screening-fine screening" flexible closed-loop location model was established. Primary screening means considering different installation position of the reliability of the ascension screening out the thresholds that meet the user reliability requirements based on existing medium voltage distribution network switch (section, contact) location and user reliability requirements. The method determines the flexible closed-loop devices position by calculating the reliability index of the solution. Therefore, the installation position of the flexible closed-loop device obtained through the primary screening is the existing segment and the

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communication switch meeting the reliability requirement of the user. FIG. 1 is the primary screening schematic diagram of the flexible closed-loop device.

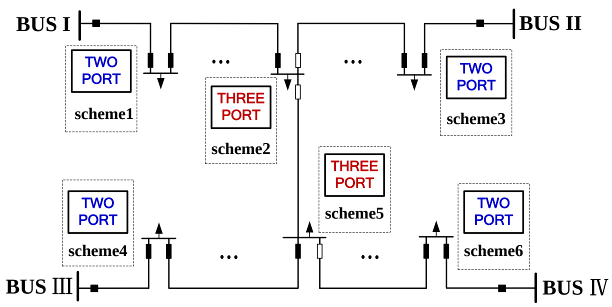

Fig. 1 Schematic diagram of primary screening

Fine screening refers to the determination of detailed evaluation indexes and it selects the final site selection scheme by a detailed comprehensive ranking and evaluation of the primary screening scheme. The objective function established is as follows:

$$G_p = \sum_{i=1}^{5} \omega_i \cdot F_{p\_i} \qquad (1)$$

Where: G_p represents the final score of fine screening scheme p; ω_i is the weight of the index i. $F_{p\text{-}i}$ is the score of index i in fine screening program p. In this paper, the entropy weight method is used to solve the weight of each index(ω_i), and the final score of each scheme(G_p) is obtained through a comprehensive of the fine screening programs by means of the ideal solution. The fine screening index system is shown in Fig2.

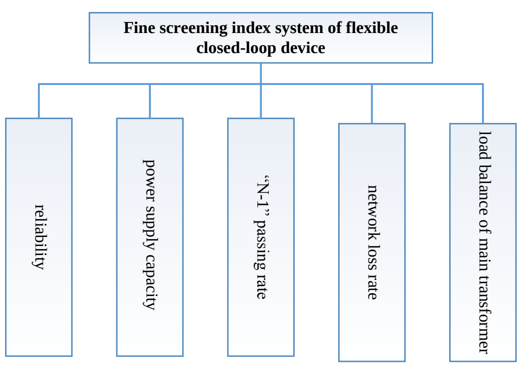

Fig. 2 Fine screening index system

(1) Reliability ($F_{p\text{-}1}$): This index is used to evaluate the effect of the flexible closed-loop device on the improvement of the reliability of the power grid after it is connected to the grid. It is mainly measured by the reliability of the power supply (RS-1).

(2)Power supply capacity ($F_{p\text{-}2}$): The power supply capacity of the distribution network is defined as the maximum load that the distribution network can carry when all feeder "N-1" check and main transformer "N-1" check are satisfied.

(3)"N-1" pass rate ($F_{p\text{-}3}$): After the flexible closed-loop device is connected to the grid, the load transfer path can be increased. This index is used to evaluate the impact on the "N-1"pass rate of the grid after the device is connected. .

(4)Work loss rate ($F_{p\text{-}4}$): After the flexible closed-loop device is connected, it can evenly distribute the feeder current and reduce the network loss. This index used to evaluate the impact of the device on the grid loss rate.

The principle of solving the index $F_{p\text{-}1}$～$F_{p\text{-}4}$can be found in the literature [6-7]

(5) Main load balance degree ($F_{p\text{-}5}$): This index is used to measure the load balance degree of the main transformer after the flexible closed-loop device is connected. It is generally considered that the more balanced the main transformer load, the more uniform the power flow distribution and the network loss, the lower the rate, and the better the voltage quality. The index calculation method is as follows：

$$B = e^{-\frac{\sigma}{\bar{\eta}}} \qquad (2)$$

Where: σ is the standard deviation of the transformer load rate; $\bar{\eta}$ is the average value of the transformer load rate; B is between (0, 1), the larger the value, the more balanced the main load.

B. Entropy-weight Ideal Solution

The entropy weight ideal solution consists of the entropy weight method and the ideal solution method. The entropy weight method is used to determine the weight of each index. On the basis of determining the weight of each index, the ideal solution is used to comprehensively evaluate each candidate plan, and then select the optimal scheme. In the power industry, there are many application cases for this method, including the selection of substations and thermal power plants, and comprehensive evaluation of transmission network construction planning[8-10]. In addition, the entropy weight ideal solution has a relatively mature application in other fields [11-12]. In view of the maturity of the algorithm, the calculation principle is detailed in the relevant references, and will not be repeated here.

III. FLEXIBLE CLOSED-LOOP DEVICE CONSTANT VOLUME METHOD

Based on the different development of regional power grids, this paper establishes three methods for determining the port capacity of flexible closed-loop devices, which are applicable to the initial stage of power grid development, slow growth period and saturation period.

Capacitance setting scheme 1: the port capacity of the flexible closed-loop device is comprehensively determined based on the net load of the feeder, that is, the capacity of the flexible closed-loop device only satisfies the current net load supply demand.

The constant volume method mainly considers that the port capacity satisfies the current grid load-to-supply demand, and separately solves the inflow demand and outflow demand of each port capacity, and finally solves the port capacity by formula (3).

$$S_{\text{port}} = \max\{\min(S_{\text{in\_max}}, S_{\text{d\_re}}), \min(S_{\text{out\_max}}, S_{\text{i\_re}})\} \quad (3)$$

Where: S_{port} is the final capacity of the port; $S_{\text{in\_max}}$ is the maximum inflow requirement of the port; $S_{\text{d\_re}}$ is the remaining capacity constraint of the direct feeder of the port; $S_{\text{out\_max}}$ is the maximum outflow requirement of the port; $S_{\text{i\_re}}$ is the remaining capacity constraint of the port interconnection feeder.

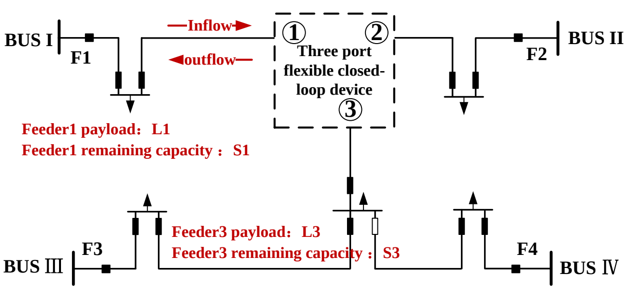

Fig. 3 Sizing method based on payload

In order to determine the final capacity of the port, we first need to solve four key indexes, as shown in Fig 3. The port 1 of the flexible closed-loop device is taken as an example to explain the four indexes.

Maximum inflow demand of the port: The maximum inflow demand of the port occurs when the feeder F2 and F3 outlet breakers are disconnected, and the feeder F1 is transferred through the port 1. Therefore, the maximum inflow demand of the port 1 is the sum of the feeders F2 and F3. And, that is, L2+L3.

Directly connected feeder residual capacity constraint: Since the power flowing into port 1 is provided through the feeder F1, the actual power that port 1 can provide when the maximum inflow demand occurs is constrained by the remaining capacity of the feeder F1, namely, S1.

Maximum outflow demand of the port: The maximum outflow demand of the port occurs when the feeder F1 outlet breaker is disconnected, and the feeder F2 and F3 are transferred through the port 1. Therefore, the maximum outflow demand of the port 1 is the load of the feeder F1, namely, L1. .

Remaining capacity constraint of the interconnect feeder: Since the power of the outflow port 1 is provided through the feeders F2 and F3, the actual power that can be provided by the port 1 when the maximum outflow demand occurs is limited by the remaining capacity of the feeders F2 and F3, that is, S2 +S3.

Application scenario 1: The grid development is in a saturated period, and the regional load is almost no longer growing. To the planned target year, the flexible closed-loop device only needs to meet the current grid load-to-supply demand.

Constant capacity scheme 2: Determine the capacity of each port based on the capacity of the direct closed feeder section of the flexible closed-loop device, that is, only considering the flexible closed-loop device to meet the maximum possible supply demand of the current grid, and not considering the expansion of the grid line in the long-term year.

This constant capacity method considers that the inflow and outflow power of each port of the flexible closed-loop device are provided by the feeder segments directly connected, and therefore, the capacity of each port should less than the rated capacity of the directly connected feeder segments. The capacity of each port determined by this method is the rated capacity of the direct-connected feeder segments.

As shown in Fig. 4, the feeder segments directly connected to the flexible closed-loop device ports 1, 2, and 3 are feeder segments F1-2, F2-2, and F3-2.The capacity of each port of the flexible closed-loop device determined by the method is respectively the rated capacity of feeder segments F1-2, F2-2, F3-2.

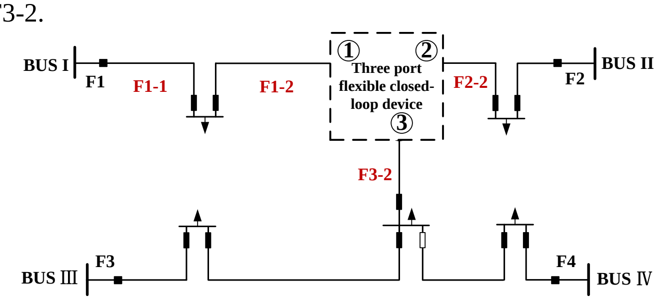

Fig. 4 Sizing method based on direct feed line

Application scenario 2: The port capacity determined by this method not only satisfies the current load demand, but also has a certain capacity margin. If the growth of regional load is slow and the remaining capacity of the current grid feeder is large, the constant volume method can be used.

Constant capacity scheme 3: Determine the capacity of each port of the device based on the capacity of the flexible closed-loop device directly connected to the feeder.

Considering the target year of planning, in order to eliminate the "bottlenecks" phenomenon of the power grid, it is necessary to increase the capacity of the "bottlenecks" feeder segments of the power grid. The flexible closed-loop device can meet the demand for power supply after the upgrade and transformation, and does not become the new "bottlenecks" of the power grid. Therefore, the capacity of each port determined by the method is the feeder capacity directly connected to each port.

Application Scenario 3: The constant volume method is similar to the constant capacity method based on the direct-connected feeder segment. In addition to the current load, the determined port capacity also considers the capacity expansion of the long-term power grid. The constant volume method can be used in the location where the regional load increases rapidly

IV. SELECTION AND CAPACITY DETERMINATION PROCESS OF FLEXIBLE CLOSED LOOP DEVICE

The selection and capacity determination process of flexible closed-loop device is as follows:

(1) Determine the intended access location of the 10kV flexible closed-loop device according to the topology of the power grid;

(2) Calculate the power supply reliability rate of the intended access position respectively, and select the access scheme that meets the user's reliability requirements as the primary screening scheme;

(3) Calculate the indexes of each primary screening scheme separately, form the original evaluation matrix of the scheme, calculate the weights of each index by entropy weight method, and comprehensively evaluate each scheme through the ideal solution to obtain the optimal access location.

(4) Analyze the development stage of the power grid, and select the corresponding constant volume method according to the planned target year power grid situation and load demand;

(5) According to the feeder capacity and feeder payload of each port, comprehensively determine the capacity of each port;

(6) According to the actual application requirements, it is finally determined that each port of the flexible closed-loop device takes the same capacity or different capacity.

V. EXAMPLE

A. Boundary conditions

Taking a 10 kV demonstration project as an example, a three-terminal example corresponding to it is established. As shown in Fig 5, the demonstration project consists of two stations and four feeders. The required parameters for the calculation of the rated capacity and load of each feeder segment are marked in Fig 5. The user reliability requirement threshold is 99.9960%.

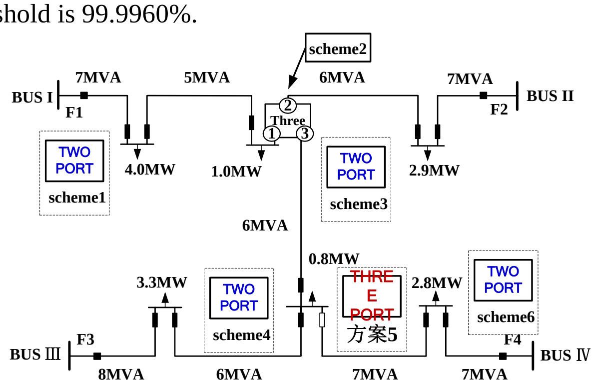

Fig. 5 Three-terminals example of demonstration project

B. Flexible closed-loop device location

According to the primary screening method of the flexible closed-loop device, after the primary screening, six candidate solutions can be obtained. The fine screening indexes of the six candidate schemes were calculated separately, as shown in Table 1.

Tab. 1 Indexes of each scheme

scheme	reliability /%	power supply capacity /（MV·A）	"N-1" passing rate /%	network loss rate /%	load balance of main transformer
1	99.997 5	11	50	5.35	0.76
2	99.997 7	17	100	5.23	0.82
3	99.997 5	11	50	5.39	0.69
4	99.997 5	11	50	5.43	0.71
5	99.997 6	17	100	5.31	0.81
6	99.997 5	11	50	5.42	0.75

After obtaining the original evaluation matrix of the scheme, the weights of each index based on the primary screening scheme are obtained by the entropy weight method, as shown in Table 2.

Tab. 2 Weight of each index

index	reliability	power supply capacity	"N-1" passing rate	network loss rate	load balance of main transformer
weight	0.278 3	0.264 7	0.264 7	0.113 7	0.078 5

After obtaining the weights of each index, combined with the standardized evaluation matrix, comprehensive evaluation of each scheme is carried out by the ideal solution, and it is determined that scheme 2 is the optimal access scheme.

Tab. 3 Comprehensive evaluation results of each scheme

scheme	1	2	3	4	5	6
relative similarity	0.116 1	**1.000 0**	0.045 1	0.024 3	0.737 4	0.070 9

C. Flexible closed-loop device constant volume

Constant volume scheme 1: A constant volume scheme based on the current payload. The current payload of feeder 1 is 5.0 MW, the current payload of feeder 2 is 2.9 MW, and the current payload of feeder 3 is 4.1 MW. Combined with the feeder capacity and load, the capacity of each port of the flexible closed-loop device based on scheme 1 can be calculated, as shown in Table 4. In the end, each port capacity can take different capacities or take the same capacity (5 MV•A).

Tab. 4 Device capacity based on payload

	index	port 1	port 2	port 3
Inflow	Port maximum inflow demand /MW	7	9.1	7.9
	Direct feeder residual capacity constraint /（MV·A）	2	4.1	3.9
Outflow	Port maximum outflow demand /MW	5	2.9	4.1
	Interconnect feeder residual capacity constraint /（MV·A）	8	5.9	6.1
Port capacity/（MV·A）		5	4.1	4.1

Constant capacity scheme 2: A constant volume scheme based on the capacity of the directly connected feeder segment. The rated capacity of the feeder segments directly connected to ports 1, 2, and 3are respectively 5, 6, and 6 MV•A. The maximum transfer capacity of each port is limited by the capacity of the direct feeder segment. Therefore, the port capacity of the flexible closed-loop device obtained by scheme 2 are 5, 6, and 6 MV•A. Each port capacity can take different capacities or take the same capacity (6 MV•A) in the end.

Constant capacity scheme 3: Constant capacity scheme based on direct feeder capacity. The feeder capacity of ports 1, 2, and 3 are respectively 7, 7 and 8 MV•A. The maximum transfer capacity of each port is limited by the capacity of the direct feeder. Therefore, the capacity of each port of the flexible closed-loop device obtained through scheme 3 is respectively 7, 7, 8 MV•A. Finally, each port capacity can take different capacities or take the same capacity (8 MV•A)

VI. CONCLUSION

The 10 kV flexible closed-loop device is mainly used to solve the problem of unsustainable closed-loop operation in the traditional distribution network. With the help of distributed automation, it can realize the rapid isolation of the fault/overhaul section and reduce short-term power supply interruption of the non-fault/ non-overhaul area, improving the reliability of the power supply. Based on the support of the 863 project "Key Technology of AC/DC Hybrid Distribution Network (2015AA050102)", this paper conducts an in-depth study on the location and volume of 10 kV flexible closed-loop devices, and establishes a flexible closed-loop device location model with strong operability. The model has been applied to the demonstration project of the 863 project, which provides theoretical support for the location and volume of the 10 kV flexible closed-loop device.

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