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The New Method of Dynamic Interval Power Flow Calculation Based on Master-Slave Control Microgrid

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Abstract. The interval power flow is a power flow analysis method with uncertain parameters as interval. It only needs to know the upper and lower bounds of the uncertainty. In order to avoid the interval iterative process of the traditional interval flow algorithm, a new method of interval flow calculation is proposed to calculate the dynamic interval flow of the master slave control microgrid. First, the affine Taylor interval expansion function model is established by combining interval numbers and affine numbers. On the basis of the dynamic dynamic interval of the active power output of the intermittent DG device, the affine interval flow model of the master and slave control microgrid is established, and the dynamic interval of the flow solution is obtained by the interval flow method based on the affine Taylor interval extension function. The method realizes the decoupling of the interval operation and the iteration operation, and can reduce the interval operation. Quantity and improvement of convergence. Finally, the correctness and effectiveness of the proposed method is verified by the simulation example of a modified microgrid system.

1. Introduction

Interval spread function is very important in interval mathematics theory. If the interval function is an interval extension function containing monotonicity of a real function, the upper and lower bounds of the value domain of the real function can be approximated by the calculation of the extended function of the interval. The form of interval expansion function mainly includes simple interval expansion, median interval expansion and Taylor interval expansion. [1-2] The extension function of Taylor interval uses polynomial approximation to express functions, and is less affected by correlation problems and wrapping effects. At present, there is not much research on Taylor interval extension function in power system and its related neighborhoods at home and abroad. Document [3-4] proposes a Taylor interval model algorithm for power system time domain simulation to overcome the shortcomings of the conventional interval algorithm. [5-6] Document applies the Taylor interval model to frequency domain analysis of circuits.

In this paper, dynamic interval power flow calculation is carried out for master slave control microgrid, and an interval power flow calculation method based on affine Taylor interval expansion function is proposed. Based on the affine number, the affine Taylor interval expansion function model is established, and the interval flow model of the master slave control microgrid is established by the
uncertainty of the intermittent DG output, and the interval flow method based on the affine Taylor interval expansion function is proposed to solve the dynamic dynamic interval of the system. Finally, an example is used to verify the correctness and effectiveness of the proposed method.

2. Master slave control micro grid dynamic interval power flow calculation process

The dynamic interval flow calculation process of the master-slave control microgrid with wind power and photovoltaic power is shown in Figure 1. On the basis of obtaining the dynamic interval of the injection power of the node, the interval flow method based on the affine Taylor interval expansion function is used to solve the dynamic interval flow of the system in the next period.

\[
x(\hat{S}) = x(S_0) + \frac{\partial^2 x(S_0)}{\partial (\hat{S})^2} S_\varepsilon + \frac{1}{2} \frac{\partial^2 x(S_0)}{\partial (\hat{S})^2} (S_\varepsilon)^2
\]

\[F(\hat{x}(S_0), S_0) = 0\]

\[S_\varepsilon = \sum_{j=1}^{N} \left( \sum_{i=1}^{N} \frac{\partial F}{\partial x_i} \frac{\partial x_i}{\partial S_j} + \frac{\partial F}{\partial S_j} \right) \bigg|_{(\hat{x}(S_0), S_0)} \bigg) S_{\varepsilon} = 0\]

\[
\frac{\partial^2 F}{\partial \hat{S}^2} \bigg|_{(\hat{x}(S_0), S_0)} (S_\varepsilon)^2 = \sum_{i=1}^{N} \sum_{j=1}^{N} \left( \sum_{p=1}^{N} \frac{\partial^2 F}{\partial x_i \partial x_p} \frac{\partial x_p}{\partial \hat{S}} \frac{\partial x_i}{\partial \hat{S}} \right)
\]

\[+2 \sum_{j=1}^{N} \frac{\partial^2 F}{\partial x_i \partial x_j} \frac{\partial x_i}{\partial \hat{S}} \frac{\partial x_j}{\partial \hat{S}} + \frac{\partial F}{\partial \hat{S}} \bigg|_{(\hat{x}(S_0), S_0)} \bigg) S_{\varepsilon}, S_{\varepsilon j} = 0\]

The concrete steps are as follows:

1) Input the parameters of the microgrid system to predict the active and reactive power dynamic intervals of the wind, photovoltaic and load of \( t_h \) in \( t_{dk} \) in the future time of the microgrid, and convert it into affine form, which makes \( t=0 \), \( k=1 \).

2) Get the injected power affine \( t_{dk} \) of each node except the balance node in \( \hat{S} \), and set \( t = t + t_{dk} \).

3) Form (15) - (17), get \( \hat{x}(S_0), \frac{\partial \hat{x}(S_0)}{\partial (\hat{S})}, \frac{\partial^2 \hat{x}(S_0)}{\partial (\hat{S})^2} \).

4) Get the \( \hat{x}(\hat{S}) \) from the formula (13) and transform it into the corresponding interval form, that is, get the interval solution of the unknown node voltage amplitude and phase angle in \( t_{dk} \).

5) Judge if \( t < t_h \), make \( k=k+1 \), then enter step 2), if not, output the dynamic interval power flow value of \( t_h \) in the future period, and end the calculation.
Figure 1. Flow chart of dynamic interval power flow calculation of master-slave control microgrid

3. Example analysis
On a computer with a G2020 processor and 2 G memory, a master-slave microgrid based on an affine Taylor interval extended function interval flow method is developed by using the simulation software Matlab R2013a.

Dynamic interval flow calculation program. The calculation results are output with 5 bit effective numbers.

3.1. WT device and PV device active power output dynamic interval results
The dynamic interval of active power output of the intermittent DG device is proposed in this paper, and the active output dynamic interval of the WT device and the PV device in the 38 node master slave control microgrid calculation system is obtained. The dynamic interval of wind velocity and light intensity of every 1 h within 1 D of a certain microgrid is predicted, and the dynamic force interval of the active power of the WT and PV devices is obtained, as shown in Figure 2 and figure 3.
As shown in figures 2 and 3, the active output interval of the WT device and the PV device varies dynamically with time. The range of variation is $[0.178, 0.1010]$ pu, $[0, 0.9291]$ pu.

3.2. Algorithm verification

The results of the voltage amplitude range of the nodes at 10:00 to 11:00 under the 2 methods are compared as shown in Table 1. Among them, the algorithm 1 is the present method, and the algorithm 2 is Monte Carlo sampling. From table 1, it can be seen that the voltage amplitude interval of nodes based on the dynamic interval flow calculation method based on the affine Taylor interval expansion function can completely contain the range of the voltage amplitude calculated by the Monte Carlo sampling method, and the results under the 2 methods are very close. It shows that the proposed method of interval flow calculation has completeness. The correctness of the method is verified.

| Node number | Algorithm 1 Lower bound/pu | Algorithm 1 Upper bound/pu | Algorithm 2 Lower bound/pu | Algorithm 2 Upper bound/pu | Node number | Algorithm 1 Lower bound/pu | Algorithm 1 Upper bound/pu | Algorithm 2 Lower bound/pu | Algorithm 2 Upper bound/pu |
|-------------|-----------------------------|----------------------------|-----------------------------|----------------------------|-------------|-----------------------------|----------------------------|-----------------------------|----------------------------|
| 1           | 1.0200                      | 1.0200                     | 1.0200                      | 1.0200                     | 20          | 1.10133                    | 1.0135                    | 1.0133                     | 1.0135                     |
| 2           | 1.0182                      | 1.0186                     | 1.0182                      | 1.0186                     | 21          | 1.1022                    | 1.1023                    | 1.1022                     | 1.1023                     |
| 3           | 1.0102                      | 1.0127                     | 1.0102                      | 1.0127                     | 22          | 1.0106                    | 1.0107                    | 1.0106                     | 1.0107                     |
| 4           | 1.0063                      | 1.0096                     | 1.0063                      | 1.0095                     | 23          | 1.0077                    | 1.0114                    | 1.0077                     | 1.0113                     |
| 5           | 1.0027                      | 1.0067                     | 1.0027                      | 1.0067                     | 24          | 1.0034                    | 1.0094                    | 1.0034                     | 1.1193                     |
| 6           | 0.9938                      | 0.9997                     | 0.9939                      | 0.9996                     | 25          | 1.0023                    | 1.0106                    | 1.0023                     | 1.0106                     |
| 7           | 0.9933                      | 1.0000                     | 0.9934                      | 0.9999                     | 26          | 0.9906                    | 0.9983                    | 0.9906                     | 0.9982                     |
| 8           | 0.9932                      | 1.0011                     | 0.9933                      | 1.0067                     | 27          | 0.9825                    | 0.9964                    | 0.9825                     | 0.9964                     |
| 9           | 0.9943                      | 1.0043                     | 0.9944                      | 0.9996                     | 28          | 0.9768                    | 0.9884                    | 0.9768                     | 0.9884                     |
| 10          | 0.9958                      | 1.0080                     | 0.9959                      | 1.0111                     | 29          | 0.9745                    | 0.9828                    | 0.9745                     | 0.9827                     |
| 11          | 0.9961                      | 1.0087                     | 0.9962                      | 1.0043                     | 30          | 0.9732                    | 0.9805                    | 0.9732                     | 0.9804                     |
| 12          | 0.9969                      | 1.0100                     | 0.9970                      | 1.0080                     | 31          | 0.9733                    | 0.9792                    | 0.9733                     | 0.9792                     |
| 13          | 1.0013                      | 1.0175                     | 1.0014                      | 1.0086                     | 32          | 0.9742                    | 0.9793                    | 0.9742                     | 0.9792                     |
| 14          | 1.0037                      | 1.0213                     | 1.0039                      | 1.0099                     | 33          | 0.9935                    | 0.9802                    | 0.9935                     | 0.9802                     |
| 15          | 1.0066                      | 1.0255                     | 1.0068                      | 1.0175                     | 34          | 1.0327                    | 1.0014                    | 1.0327                     | 1.0014                     |
| 16          | 1.0104                      | 1.0308                     | 1.0105                      | 1.0213                     | 35          | 1.0100                    | 1.0066                    | 1.0100                     | 1.0065                     |
| 17          | 1.0193                      | 1.0429                     | 1.0195                      | 1.0254                     | 36          | 1.0074                    | 1.0100                    | 1.0074                     | 1.0100                     |
| 18          | 1.0267                      | 1.0528                     | 1.0269                      | 1.0428                     | 37          | 0.9797                    | 1.0214                    | 0.9797                     | 1.0212                     |
| 19          | 1.0176                      | 1.0179                     | 1.0176                      | 1.1079                     | 38          | 1.1022                    | 0.9856                    | 0.9797                     | 0.9856                     |
3.3. Calculation results of dynamic interval power flow grid connected operation mode

The dynamic interval power flow calculation in the future 1 D is carried out by using the method proposed in this paper. The voltage amplitude range of node voltage at 11:00 to 12:00 period is shown in the appendix table A1. The dynamic range of node voltage amplitude in node 35 and node 37 in 1 D is shown in Appendix A2. In A2, the dotted line is the upper bound value and the real line is the lower bound value.

Simulation analysis:
1) Comparison table 1 and appendix table A1 show that the voltage amplitude range of the same node in 1 D at different periods is different; in addition, the voltage amplitude of the node 35 at the 10:00 to 11:00 period is in the limit, and the voltage amplitude of all nodes in the period of time is in the qualified range. It is shown that the dynamic interval power flow calculation in microgrid can effectively predict the occurrence of nodal voltage limits and has good engineering applicability.
2) From the appendix diagram A2 (a), it is known that the range of voltage amplitude of node 35 in 1 D is [0.965 1, 1.060 6] pu, and the maximum value of the voltage amplitude of node 35 at 10:00 to 11:00 time is 1 D. This is due to the WT device on node 35, is a balanced node, and the node 1 has a non intermittent DG device, which is a PQ node, and uses this method to calculate the dynamic interval power flow in the future 1 D. Set Case1: the injection power of a given node 1 is 0.21+j0.22. Set Case2: the injection power of a given node 1 is 0.5+j0.52. The amplitude and phase angle of each node at 14:00 to 15:00 are obtained under Case1, as shown in Appendix A3. Case1 and Case2 get the dynamic range of the voltage amplitude of node 1 within 1 D as shown in Figure 4.

Simulation analysis:
1) From the appendix diagram A3, it is known that under the 14:00 - 15:00 period of 1 D, the voltage amplitude and phase angle range of the system node are [0.965 4, 1.028 3], [0.1427, 0], all in the range of qualification.
2) From the figure 4 (a), it is known that the range of voltage amplitude of the node 1 under Case1 is [0.936 3 and 0.988 4], and the limit of voltage appears; and as shown in Figure 4 (b), the range of voltage amplitude of node 1 under Case2 is [0.936 3, 0.988 4], in a qualified range. It is shown that increasing the output of non intermittent DG devices in the master slave control microgrid system under islanding operation mode is conducive to improving the voltage level of the system.

![Figure 4. Dynamic interval of node 1 voltage amplitude under different set](image)

4. Conclusion
In this paper, the interval power flow method based on affine Taylor interval expansion function is proposed, and the dynamic interval power flow calculation of microgrid is carried out. The method transforms the solution of interval power flow into a set of deterministic power flow equations and 2 matrix equations. The results and analysis of the example show that:
1) The interval flow method based on the extended function of the affine Taylor interval is proposed, which realizes the decoupling of the interval operation and the iterative operation, and can solve the
problem of the convergence of the traditional interval iterative method and the oversize calculation of the interval.

2) The dynamic interval flow calculation of the microgrid can calculate the dynamic uncertainty of the active power output of the intermittent DG device, which is suitable for the inaccurate probability distribution of the result of the output prediction but can obtain the upper and lower bounds of the predicted value.

The dynamic range flow of the microgrid gives the dynamic range of the voltage of each node in a certain period of time, which can provide some reference for the analysis and control of the steady state operation of the microgrid.

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