DESIGN OF POWER NETWORK FAULT DIAGNOSIS BASED ON TIME SERIES MATCHING

by

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Common grid fault diagnosis does not fully utilize the alarm timing information generated by the fault. To solve this problem, this paper proposes a fault diagnosis method based on time series. The method analyzes the alarm hypothesis sequence generated by the grid fault and the time sequence actually received by the dispatch center, and utilizes the discrete characteristics of the edit distance and reflects the event discreteness and time continuity of the alarm information by adding the time distance. The calculated data of the similarity between the two sequences and the confidence of the alarm hypothesis sequence determine the faulty component.

Key words: *power network, fault diagnosis, time series, confidence*

Introduction

With the continuous development of the power system dispatching automation system, the unresolved methods of power grid fault diagnosis have also appeared one after another. [1-9]. The fault alarm information collected by the dispatching center is more and more comprehensive [10-17]. Throughout the entire development history of power system fault diagnosis methods, most of the methods that have been proposed so far have not been able to fully utilize the timing of many fault information for some complicated faults caused by external factors or human error [18-23]. There are situations where accurate diagnostic results are not available, and if this is the case, an incorrect diagnosis may result.

In this paper, the method of judging the fault point by comparing the alarm hypothesis sequence of the fault point and the sequence obtained by the dispatch center in the event of grid fault is proposed. To diagnose faults by this method, the first step is to establish a network to obtain a set of suspected fault components. Then, build a common model for the relay protection devices involved in the suspected faulty components, and then calculate the confidence of the alarm hypothesis. The distance between the hypothesis sequence and the time series actually received by the dispatch center further identifies the components that are actually faulty and their associated causes. Different from the existing methods, the method for diagnosing faults in this paper can make full use of the timing information after the fault, which can ensure lower time complexity and further ensure higher efficiency and high accuracy.

Time series model

When analyzing the time series, the sequence segment analysis should be carried out to find out the similarities and differences between different segments in the same time interval

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or the same segment in the inconsistent interval, and the correlation law is obtained. After mining the time series, we can generate a pattern that helps us analyze by using the pattern to find relevant sequence features in the database.

First, define a few formulas $x = (v, t)$ is an element in the time series (where v is the alarm information, t is the time), further defines $v = (A, \Delta t, S)$, where A represents an alarm event, which can refer to an accident in the power grid, which can be short-circuit, open circuit, circuit breaker rejection and other events, or may refer to the timing information obtained by the control center, Δt – the difference between the time when two events occur, which is used to explain the time accuracy, t and Δt together as an indicator of time, so event A occurs:

$$\left[t-\frac{\Delta t}{2}, t+\frac{\Delta t}{2}\right]$$

The S is the fuzzy item identifier bit:

$$\begin{cases} S=1, \text{ element } x=(v,t) \text{ is a mandatory item} \\ S=0, \text{ element } x=(v,t) \text{ is a fuzzy item} \end{cases}$$

When the grid fails, the aforementioned missed report and false alarm information cannot be uploaded to the dispatch center, so this type of information needs to be processed separately, and in this case, the dispatcher cannot determine whether the circuit breaker is acting (circuit breaker action refers to the occurrence of the circuit breaker). The phenomenon that the insulation layer is broken after the action, the circuit breaker does not move is the circuit breaker's refusal phenomenon). Based on the above phenomenon, the real action of the circuit breaker cannot be obtained from the alarm information when the circuit breaker is rejected, and it cannot be simply regarded as the phenomenon of false negatives and false alarms. The information is blurred by introducing the concept of ambiguity. It is beneficial to distinguish this type of information and improve the corresponding fault diagnosis accuracy.

In this model, when A is one of the following cases, element A is a fuzzy item:
– A_i refers to the failure of the grid component and
– $A(i + 1)$ is the circuit breaker trip and A_i is the failure protection corresponding to the circuit breaker.

Protection general model

After the grid fails, the general protection model built is shown in fig. 1.

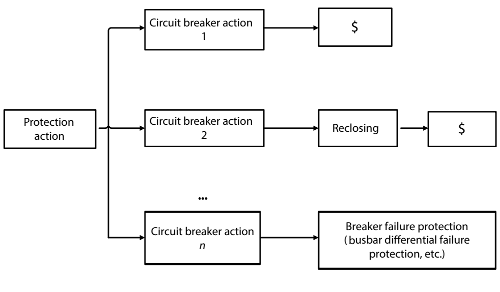

Figure 1. Protection configuration general model

As can be seen from fig. 1, all time series starting from the action of the protection device is started with $ or another protection start action, and when the other protection starts to act as a stop point, the action of the protection device it is the trigger point of another time series, and thus a time series longer than the original time series can be formed after the connection. In this way, a set of reference time series can be obtained.

When a fault occurs, the protection device action causes each element in the associated time series group G to be triggered in sequence, and a time series with good accuracy is obtained after the scheduling center is concentrated, wherein the time, t, of the event is determined by the setting time of the protection device. The length of time is determined by the time error of the event. As an example, let's take fig. 2 as an example.

Set: L_1 at t = 0, a non-permanent single-phase ground fault occurs and the reclosing is successful.

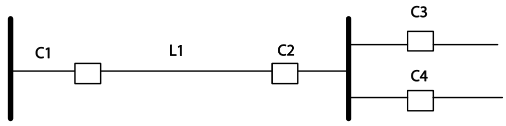

Figure 2. Power system example

Alarm hypothesis timing sequence set

From the monitor, the alert information atmosphere: major accidents, unusual action measures of the protection device, exceeding the limit, location and alarm reset, and other information.

The alarm hypothesis time series refers to a time series that does not actually occur. The alarm hypothesis represents the failure of the component and the moment when the component fails. Study the alarm logic relationship and use it as a basis to build a model of the alarm between the model obtained from the protection configuration model. There are 2 steps to complete a full alarm process, get a library of grid information and analyze the obtained alarms and get the results. There should be steps for calculation and reasoning.

Two timing characteristics of the alert:

– fault zone: the area formed by all the suspected faulty components judged by the action of the protection device and
– timing of protection: it consists of the setting of protection and the time of action.

The safe and stable operation of the system is closely related to the reliability of the protection after the accident, and the components in the power grid are protected from the protection device. When the grid component fails, the primary protection of the component detects an alarm symptom and responds to disconnect the relevant circuit breaker; when the system fails, a short circuit occurs like the transmission-line, transformer, busbar or other main equipment*, etc.* When the action is issued and the trip command is issued, and the circuit breaker of the faulty device refuses to act, it is called a breaker failure. There are many reasons for the failure of the circuit breaker, such as the failure of the circuit breaker operating mechanism, the failure of the circuit breaker trip coil, and the disappearance of the DC power supply.

In fig. 2, if L_1 has a non-permanent single-phase ground fault at time $t = 0$, the protection on both the left and right sides of line L_1 will operate.

Confidence of timing sequence elements

Confidence is the measure of the true reliability of an event, if the condition is met. The measure is a value between 0 and 1, ie probability. If the distance between the sequence X and the real sequence Y is d, the smaller the d is, the higher the confidence of the hypothesis is, and the confidence level C_X is defined:

$$C_X = \begin{cases} 1, \ D(X,Y) \le 1 \\ \dfrac{1}{D(X,Y)}, \ 1 < D(X,Y) \le 10 \\ 0.1, \ D(X,Y) > 10 \end{cases} \tag{1}$$

When the distance between the two sequences is small enough to be negligible, the hypothesis $C_X = 1$.

In the alarm hypothesis time series, multiple hypothetical sequences $X_1, X_2, \ldots X_n$ may all contain the same element $x_1 = [v_i, = (A_i, \Delta t_i, S_i), t_i]$. If $X_1, X_2, \ldots X_n$ is concurrent, the confidence of X_i should be the average of the time series $X_1, X_2, \ldots X_n$ confidence. If $X_1, X_2, \ldots X_n$ is mutually exclusive, the max value in the confidence of $X_1, X_2, \ldots X_n$ should be taken as the confidence X_i of the element. That is:

$$C_{x_i} = \begin{cases} C_X, \; i = |\mathrm{X}| \\ C_{x_{i+1}}, \; f \text{ does not exist and } i < |\mathrm{X}| \\ \dfrac{\sum_{j=1}^{n} \mathrm{C}_{j,x_{i+1}}}{n}, \; f = 1 \text{ and } i < |\mathrm{X}| \\ \max\left(C_{j,x_{i+1}}\right), \; f = 0 \text{ and } i < |\mathrm{X}| \end{cases} \tag{2}$$

The eqs. (1) and (2) are used to calculate the distance between the sequences and the confidence of the components, so that the fault can be judged efficiently.

Timing sequence matching and fault diagnosis

After the grid fault occurs, the suspected faulty component is isolated in the power outage area by the observed tripping phenomenon of the circuit breaker. The components in the domain have the probability of being suspected faulty components. After the fault occurs, the relevant relay protection equipment automatically cuts off the corresponding circuit breaker. The component is separated from the entire system. At this time, the fault range can be determined by the disconnected circuit breaker timing information. The determination of the range is usually determined after the system is gradually stabilized. At this time, the dispatch center has obtained a more comprehensive fault. Data these data can constitute an alarm sequence, and it is impossible to continue to change. The diagnosis process is shown in fig. 3.

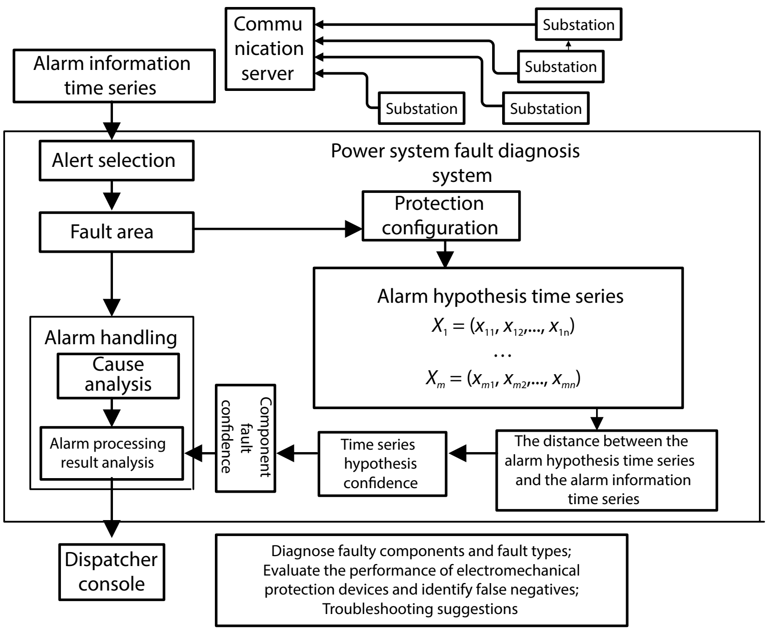

Figure 3. Power system fault diagnosis diagram based on time series matching

According to the figure, the operation of each of the processes shown therein is given here. Firstly, a passive area is obtained. After the fault is stabilized, the suspected faulty components are separately separated to form a power outage zone. All the grid components in the domain are suspected of being faulty, thus generating a set of suspected faulty components. Secondly, determining the power-off zone after that, the suspected alarm component in the area is used according to the relevant regulations. The circuit breaker that exhibits the trip action due to the suspicious component should be diagnosed centrally. The edge of the power-off domain must be a broken circuit breaker, so the suspicious component is modeled. The time series formed by the relay device ends with $ or other relay protection device, and the set of hypothesis sequences can be charged based on the model of the protection device and then, the equation is used to obtain the hypothesis sequence and the real sequence. Distance, then use the equation to calculate C_X, further determine the faulty component; finally, summarize and analyze the cause of the fault and avoid the same fault again.

Modified diagnostic method

In fact, due to external interference and the factors of the device itself, it cannot be 100% unaffected by these factors. Based on the optimization of fault diagnosis, it should be able to pre-process the obtained time series information without obtaining high-efficiency diagnosis results. An optimized method.

If the potential of the alarm hypothesis sequence X is n ($n \geq 3$), and the edit distance between X and the actual sequence Y is $d(0 < d \leq n/3)$, then there must be some element $\boldsymbol{x}_1 = [\boldsymbol{v}_i, = (\boldsymbol{A}_{xi}, \Delta\boldsymbol{t}_{xi}, \boldsymbol{S}_{xi}), \boldsymbol{t}_{xi}]$ in Y. There is no corresponding alarm message, *i. e.*, $xi| \notin Y$.

At this time, it can be assumed that the $\boldsymbol{y}_1 = [\boldsymbol{v}_{yi}, = (\boldsymbol{A}_{xi}, \Delta\boldsymbol{t}_{xi}, \boldsymbol{S}_{xi}), \boldsymbol{t}_{xi}]$ has a missing notification due to some factors, and an event Y_i that does not exist in the sequence Y is added to create an initial alarm sequence Y' *(i. e.*, an optimized alarm sequence). The alarm hypothesis time series X containing the event A_{xi} is then re-calculated to determine the operational confidence of the component. In this case, the credibility of the event Y_i that does not actually exist is measured by the eq. (3):

$$\boldsymbol{C}'_{x_i} = \frac{\boldsymbol{n} - \boldsymbol{d}}{\boldsymbol{n}} \boldsymbol{C}_{x_i} \tag{3}$$

In eq. (3), C_{xi} refers to the confidence obtained by using two sequences X and Y', n is the potential of X, the magnitude of n can reflect the number of underreports inversely, d refers to the distance between X and Y, and its size the relationship between n is $\boldsymbol{d} \propto \boldsymbol{\alpha}\ (1/\boldsymbol{n})$, and the small d indicates that the confidence of $\boldsymbol{y}_1 = [\boldsymbol{v}_{yi}, = (\boldsymbol{A}_{xi}, \Delta\boldsymbol{t}_{xi}, \boldsymbol{S}_{xi}), \boldsymbol{t}_{xi}]$ is high.

Modelling simulation

The core idea of implementing modelling: in the protection general model, the final item is divided into two types with or without the terminator. When there is a terminator, the value is directly given, there is no terminator $ and other protection measures are taken. At the time, the value is assigned by a recursive method until the last item is the terminator.

The specific implementation steps are:

According to the previous, the protection configuration model when using MATLAB for simulation can be expressed as:

- Element corresponding to the alarm information of the component failure), (the element in the protection action timing information, there is 0 or 1.
- Element corresponding to the alarm information of the component failure), (protecting the elements in the operation timing information, no 0 or 1.

The elements of each time series are represented by $\boldsymbol{x}_\mathrm{i} = (\boldsymbol{v}_i, t_i) = [(\boldsymbol{A}_{ni}, \Delta\boldsymbol{t}_{ni}, \boldsymbol{S}_{ni}), \boldsymbol{t}_{ni}]$.

In the protection configuration model, it is first judged that there is no 0 or 1 in the final item; if there is 0 or 1, then it is judged whether there is a terminator $ indicating the end of the protection action, and if there is a terminator $, the second to last item of an element in the sequence Direct assignment, if there is no terminator $, continue to find the next item, then the time, *t*, should be added to the time, *t*, of the previous item, use the concept of recursion search until the terminator is found; if there is no 0 or 1, then It is necessary to determine whether there is a terminator indicating the end of protection. As with the previous operation, if there is a terminator, the second-order term of an element in the sequence is directly assigned. Otherwise, the next item is continued. The *t* should be added to the time of the previous item, using recursion until the terminator is found. Unlike the case where the previous term is 1, the final term is 0. There is no common solution in the case of the terminator.

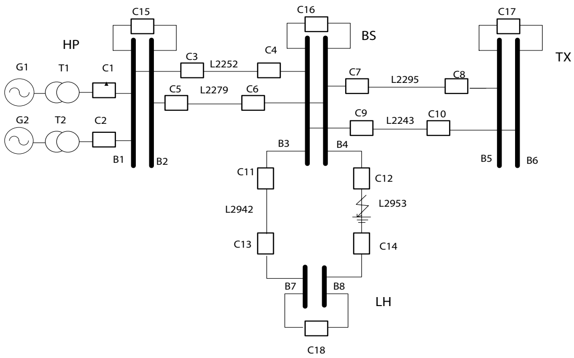

Figure 4. Wiring diagram of parts of Guangzhou power system

Case study

Based on the previous description, a general algorithm model is established by software. The following explains the fault case actually occurring in a city in Guangdong Province.

Case: the case of Guangdong Province, the wiring diagram is shown in fig. 4.

First, the number of alarm information involved in the definition is shown in tab. 1:

Table 1. Alert message number

Definition	Alert content
a_1	BS line L2943 longitudinal differential protection action (RCS-931BM)
a_2	LH line L2943 longitudinal differential protection action (RCS-931BM)
a_3	BS C_{12} circuit breaker opens
a_4	LH C_{14} circuit breaker opens
a_5	BS C_{12} breaker failure protection
a_6	BS C_{16} circuit breaker opens
a_7	BS C_6 circuit breaker opens
a_8	BS C_7 circuit breaker opens
a_9	B4 bus differential protection
a_{10}	BS C_{12} circuit breaker closing
a_{11}	LH C_{14} circuit breaker is closed

The information actually received by the control center after the fault is recorded in tab. 2.

Table 2. Alerts received by the control center

Time	Content	Number	Element value
0	BS L2943 longitudinal differential protection action (RCS-931BM)	x_1	[(a_1, 0.1), 0]
2	LH L2943 longitudinal differential protection action (RCS-931BM)	x_2	[(a_2, 0.1), 2]
49	BS C_{12} circuit breaker opens	x_3	[(a_3, 0.1), 49]
50	LH C_{14} circuit breaker opens	x_4	[(a_4, 0.1), 50]
279	BS C_{12} breaker failure protection	x_5	[(a_5, 0.1), 279]
328	BS C_{16} circuit breaker opens	x_6	[(a_6, 0.1), 328]
330	BS C_6 circuit breaker opens	x_7	[(a_7, 0.1), 330]
332	BS C_7 circuit breaker opens	x_8	[(a_8, 0.1), 332]

Alarm sequence obtained by the control center $X = < x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8 >$.

The failure analysis process is as:

– After searching all the passive areas in the system, you can pick out three suspicious fault components: line L2943, circuit breaker C_{12} and bus B_4.
– According to the regulations of relay protection equipment, a protection model should be built for all the protection equipment involved in suspected faulty components.

The types of protection and protection configuration models used for suspected faulty components are shown in tabs. 3 and 4, respectively.

Table 3. Suspicious faulty original protection device

Grid component	Protection equipment
Line L2943	BS line L2943 main protection LH line L2943 main protection
Generator B_4	Generator B_4 protection
Breaker C_{12}	Breaker C_{12} failure protection

The relationship between the three suspected faulty components and the generic model of the protection configuration:

$$\left\langle \left[\left(\text{route }\mathbf{L}2943\text{ malfunction},10,0\right),-20\right],\begin{Bmatrix}\left[\left(\boldsymbol{a}_1,10,1\right),0\right]\\ \left[\left(\boldsymbol{a}_2,10,1\right),0\right]\end{Bmatrix},1\right\rangle$$

$$\left\langle \left[\left(\text{ malfunction }\mathbf{B}_4\text{ malfunction},10,0\right),-20\right],\left[(\boldsymbol{a}_9,10,1),0\right]\right\rangle$$

$$\left\langle \left[\left(\text{ malfunction }C_{12}\text{ malfunction},10,0\right),0\right],\left[\left(\boldsymbol{a}_5,10,1\right),200\right]\right\rangle$$

Because when line L2943, circuit breaker C_{12}, and bus B_4 fail, there is no ability to upload information, so the fuzzy item flag should be zero. Using the information shown in tab. 3, an alarm sequence hypothesis set of suspected faulty elements can be formed by unfolding the built-in generic model.

– Let both a and b have a value of 5. Taking the line L2943 as an example, the relevant data can be obtained by calculation, as shown in tab. 5.

Table 4. Protection configuration model

Protection configuration	Associated time series G
BS line L2943 main protection	$\left\langle [(a_1,10,1),0], \begin{pmatrix} \langle [(a_3,10,1),50],[(a_{10},10,1),1050],\$ \rangle \\ \langle [(a_3,10,0),50],[(a_5,10,1),280] \rangle \end{pmatrix}, 0 \right\rangle$
LH line L2943 main protection	$\langle [(a_2,10,1),0],[(a_4,10,1),50],[(a_{11},10,1),1050],\$ \rangle$
Busbar B_4 protection	$\left\langle [(\boldsymbol{a}_9,10,1),0], \begin{bmatrix} \langle [(\boldsymbol{a}_3,10,1),50],\$ \rangle \\ \langle [(\boldsymbol{a}_6,10,1),50],\$ \rangle \\ \langle [(\boldsymbol{a}_7,10,1),50],\$ \rangle \\ \langle [(\boldsymbol{a}_8,10,1),50],\$ \rangle \end{bmatrix}, 1 \right\rangle$
Circuit breaker C_{12} failure protection	$\left\langle [(a_5,10,1),0], \begin{bmatrix} \langle [(a_4,10,1),50],\$ \rangle \\ \langle [(a_6,10,1),50],\$ \rangle \\ \langle [(a_7,10,1),50],\$ \rangle \\ \langle [(a_8,10,1),50],\$ \rangle \end{bmatrix}, 1 \right\rangle$

Table 5. Line L2943 data

Alarm hypothesis time series	D_{edit}	D_{dtw}	D	C_x	Component fault confidence
$\langle [(a_1,10,1),0],[(a_3,10,1)50],[(a_{10},10.1),1050] \rangle$	1	0	5	0.2	
$\langle [(a_1,10,1),0],[(a_3,10,0),50],[(a_5,10,1),280],[(a_4,10,1),330] \rangle$	0	0	0	1	
$\langle [(a_1,10,1),0],[(a_3,10,0),50],[(a_5,10,1),280],[(a_6,10,1),330] \rangle$	1	0	5	0.2	
$\langle [(a_1,10,1),0],[(a_3,10,0),50],[(a_5,10,1),280],[(a_5,10,1),280] \rangle$	0	0	0	1	
$\langle [(a_1,10,1),0],[(a_3,10,0),50],[(a_5,10,1),280],[(a_8,10,1),330] \rangle$	1	0	5	0.2	
$\langle [(a_2,10,1),0],[(a_4,10,1)50],[(a_{11},10,1),1050] \rangle$	0	0	0	1	
$\langle [(a_2,10,1),0],[(a_4,10,0),50],[(a_5,10,1),280],[(a_6,10,1),330] \rangle$	1	0	5	0.2	1
$\langle [(a_2,10,1),0],[(a_4,10,0),50],[(a_5,10,1),280],[(a_7,10,1),330] \rangle$	0	0	0	1	
$\langle [(a_2,10,1),0],[(a_4,10,0),50],[(a_5,10,1),280],[(a_8,10,1),330] \rangle$	1	0	5	0.2	

– The confidence of the hypothesis can be obtained by the distance between the hypothesis sequence and the actually received sequence, and the confidence of the suspected faulty component is obtained by further obtaining the confidence of the component action.

Table 6. Equation calculated data

Malfunction	Confidence	Failure time
L2943 Line fault	1	The fault occurs at t = –20 ms (±10ms)
C_{12} failure	0.8 (Failure protection action)	Time is t = 0 ms (±10ms)
Generator B_4 failure	0.2	–

– Based on the diagnosis results, it can be determined that the faulty component is L2943, and C_{12} is rejected. Between the time series and the actual sequence of the L2943 alarm hypothesis, $D_{\text{edit}} = 0$ and $D_{dtw} = 0$, after the fault occurs, the protection device operates correctly and the alarm timing information is also intact.

The actual situation is:

At $t = -14$ ms, the line L2943 fails, the refinery station main protection correct action and the circuit breaker C_{14} is successfully tripped; the Bishan station main protection also acts and tries to trip the circuit breaker C_{12}, but because of the open circuit the device C_{12} is rejected, so that the breaker C_{12} fails to be protected, and the circuit breaker C_6, the circuit breaker C_7, and the circuit breaker C_{16} on the bus B_4 are tripped.

Table 7. Diagnostic result

Faulty component	Confidence C_X	Failure moment
L2943	1	t = –20 ms (±10 ms)
C_{12}	0.8	t = 0 ms (±10 ms)
Generator B_4	0.2	

According to the data in tabs. 6 and 7, the faulty components are line L2943 and circuit breaker C_{12}.

Conclusion

The method of fault diagnosis proposed in this paper makes full use of the characteristics of time series information. The improved distance method is used to measure the similarity between two alarm sequences, and the fault value is determined by the value of the confidence value. This method is better explained. The high efficiency and high speed required to solve the problem required in the fault setting specification can identify the alarm without any mistakes under complicated or concurrent faults, and the time complexity is low and the calculation speed is fast.

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