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Editorial Board

Title

LOSS REDUCTION IN RADIAL DISTRIBUTION SYSTEMS USING PLANT GROWTH SIMULATION ALGORITHM

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Abstract:

This paper aims to investigate the optimal switching sequence to maintain radial nature of distribution network for minimal active power losses and an improved voltage loads. The network configuration has been declared as a method for power and energy saving at nearly no cost. A network configuration optimization approach based on the plant growth simulation algorithm (PGSA), is specially suited to large-scale distribution systems. The change in Network configuration is achieved by closing or opening of switches in such a way that the radiality of the Network is maintained. An elegant design method of the decision variables, which describes the radial feature of the distribution network and considerably reduces the dimension of the variables in the solved model, is developed. Moreover, a detailed description on switch states further improves the efficiency of calculation. The proposed approach is applied to a 33-bus sample system and large-scale real system.

Index Terms— Distribution system, network configuration optimization, plant growth simulation algorithm (PGSA), power loss reduction.

I. INTRODUCTION:

Network Reconfiguration entails altering the topological structure of distribution feeders by changing the open/close status of the switches in these feeders under both normal and abnormal operating conditions. The benefits of feeder reconfiguration include restoring power to outaged portions of a feeder in a timely manner which improves the value of service to customers by reducing average outage time, relieving of overloads on feeders by shifting load in real-time to adjacent feeders which could defer capital expansion projects, and reducing resistive line losses which could reduce the operating cost of a distribution system. The reconfiguration takes advantages of specific distribution network structure and customer load varying nature. Most distribution networks operate radially, even though there are several interconnecting tie lines available to increase the system reliability.

The purpose of network reconfiguration is to produce the minimum loss possible under the circuit's capacity constraint. In practical application, the operational constraint of the number of switching operations also needs to be carefully examined, since frequent operation of the switches may result in malfunction. Given the structure of the network and the location of the switchable branches, the difficulty of 'optimum reconfiguration' lies in the identification of that on/off state of all switchgears which enable a minimum loss radial network to be obtained for a given instantaneous distribution of loads at various nodes.

Plant growth simulation algorithm (PGSA) is a new and efficient method for the network optimization of power distribution systems, where the objective is to minimize the total real power loss. The advantages of the developed approach over previously published random algorithms are that it does not need to construct a optimization goal by incorporating the constraints into the objective function in barrier terms, which averts the trouble to determine the barrier factors and makes the increase/decrease of constraints convenient, and that it does not need any external parameters such as crossover rate, etc., and that it adopts a guiding search direction that changes dynamically as the change of the objective function. This paper presents an approach to minimize the total system losses by using the plant growth simulation algorithm (PGSA) to optimize the network configuration of the distribution system while satisfying some constraints. A novel design of the decision variables remarkably decreases the dimension of the variables in the solved model. A detailed description on switch state is also proposed, and it further improves the efficiency of calculation.

II. PLANT GROWTH SIMULATION ALGORITHM:

The plant growth simulation algorithm is based on the plant growth process, where a plant grows a trunk from its root; some branches will grow from the nodes on the trunk; and then some new branches will grow from the nodes on the branches. Such process is repeated, until a plant is formed. Based on an analogy with the plant growth process, an algorithm can be specified where the system to be optimized first "grows" beginning at the root of a plant and then "grows" branches continually until the optimal solution is found. The plant growth simulation algorithm characterizes the growth mechanism of plant phototropism, is a bionic random algorithm. It looks at the feasible region of integer programming as the growth environment of a plant and determines the probabilities to grow a new branch on different nodes of a plant according to the change of the objective function, and then makes the model, which simulates the growth process the growth process of a plant, rapidly grow towards the light source i.e.; global optimum solution.

A. Growth laws of a plant

Biological experiments proved the following facts about the growth laws of a plant.

1) In the growth process of a plant, the higher the morphactin concentration of a node, the greater the probability to grow a new branch on the node.

2) The morphactin concentration of any node on a plant is not given beforehand and is not fixed. It is determined by the environmental information of a node, and environmental information of a node depends on its relative position on the plant. The morphactin concentrations of all nodes of a plant are allowed again according to the new environment information after it grows a new branch.

B. Probability model of plant growth

Probability model is established by simulating the growth process of a plant phototropism. In the model, a function **g(Y)** is introduced for describing the environment of the node **Y** on a plant. The smaller the value of **g(Y)**, the better the environment of the node **Y** for growing a new branch. The main outline of the model is as follows: A plant grows a trunk M, from its root B_o . Assuming there are k nodes $B_{M1}, B_{M2}, B_{M3}, \ldots B_{MK}$ that have better environment than the root B_O on the trunk M , which means the function g(Y) of the nodes and satisfy $g(B_{Mi}) < g(B_o)$ then morphactin concentrations $\mathbf{C_{M1}, C_{M2}, \ldots C_{Mk}}$ of nodes $\mathbf{B_{M1}, B_{M2}, B_{M3}, \ldots B_{MK}}$ are calculated using

$$C_{Mi} = (g(B_o) - g(B_{Mi}))/\Delta_1 \quad (i=1,2,3,\ldots k) \qquad \ldots(1)$$

Where $\Delta 1 = \sum_{i=1}^{n} (g(Bo) - g(BMi))$

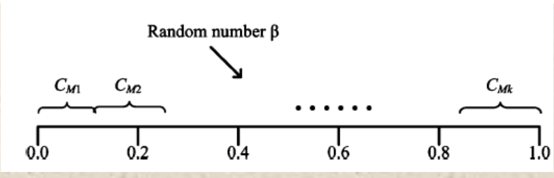

Fig. 1. Morphactin Concentration State Space

The significance of (1) is that the morphactin concentration of a node is not dependent on its environmental information but also depends on the environmental information of the other nodes in the plant, which really describes the relationship between the morphactin concentration and the environment. From (1), we can derivate $\sum C_{Mi}=1$, of the nodes form a state space shown in Fig. 1. Selecting a random number β in the interval [0, 1] and will drop into one of C_{M1}, C_{M2}, ….C_{Mk} in Fig. 1, then the corresponding node that is called the preferential growth node will take priority of growing a new branch in the next step. In other words, B_{MT} will take priority of growing a new branch if the selected β satisfies $0 \leq \beta \leq \sum_{i=1}^{T} C_{Mi}$. (T=1) or $\sum_{i=1}^{T-1} C_{Mi} \leq \beta \leq \sum_{i=1}^{T} C_{Mi}$ (T=2, 3, 4, 5…k) .For example, if random number β drops into C_{M2} , which means $\sum_{i=1}^{1} C_{Mi} \leq \beta \leq \sum_{i=1}^{2} C_{Mi}$ then the node B_{M2} will grow a new branch m . Assuming there are q nodes, which have better environment than the root $\mathbf{B_O}$, on the branch m, and their corresponding morphactin concentrations are C_{m1},C_{m2},….C_{mq}. Now, not only the morphactin concentrations of the nodes on branch m, need to be calculated, but also the morphactin concentrations of the nodes except B_{M2} (the morphactin concentration of the node becomes zero after it growing the branch) on trunk need to be recalculated after growing the branch . The calculation can be done using (2), which is gained from (1) by adding the related terms of the nodes on branch m and abandoning the related terms of the node $\mathbf{B_{M2}}$

$$C_{Mi}= (g(B_o)- g(B_{Mi}))/(\Delta_1+ \Delta_2) \quad (i=1,2,3,\dots k)$$

$$C_{Mj}= (g(B_o)- g(B_{Mj}))/(\Delta_1+ \Delta_2) \quad (j=1,2,3\dots q) \qquad \dots(2)$$

Where $\Delta 1=\sum_{i=1}^{k}(g(Bo) - g(B_{Mi}))$

Where $\Delta 2=\sum_{j=1}^{q}(g(Bo) - g(B_{Mj}))$

We can also derivate $\sum_{i=1}^{k} C_{Mi}(i \neq 2)+ \sum_{j=1}^{q} C_{Mj} =1$ from(2). Now, the morphactin concentrations of the nodes (except $\mathbf{B_{M2}}$) on trunk M and branch m will form a new state space. A new preferential growth node, on which a new branch will grow in the next step, can be gained in a similar way as $\mathbf{B_{M2}}$. Such process is repeated until there is no new branch to grow, and then a plant is formed. From the viewpoint of optimal mathematics, the nodes on a plant can express the possible solutions; g(Y) can express the objective function; the length of the trunk and the branch can express the search domain of possible solutions; the root of a plant can express the initial solution. The preferential growth node corresponds to the basic point of the next searching process. In this way, the growth process of plant phototropism can be applied to solve the problem of integer programming.

III. NETWORK OPTIMIZATION BASED ON PGSA:

A. *Design of Decision Variables*

This project presents an approach to minimize the total system losses by using PGSA to optimize the network configuration of the distribution system while satisfying some constrains. A novel design of the decision variables remarkably decreases the dimension of the decision variables in the solved model. A detailed description on switch states further improves the efficiency of calculation. In distribution network optimization, the switch is usually selected as the decision variable. It can be assigned either **0** or **1**, means open switch or closed one, respectively. It is simple to understand, but their exist two problems.

1) The number of possible network states grows exponentially with the number of switches, making unsuitable for large distribution system problems.

2) A lot of unfeasible solutions will appear in the iterative procedure ,which decreases the efficiency of calculation , and sometimes the optimal solution is not gained.

In a distribution system the number of independent loops is equal to number of tie switches. So, the problem of network optimization is identical to the problem of selection of appropriate tie switch for independent loop so that system active power loss can be minimized. So, we employ independent loops rather than switches as decision variables, thus reducing the dimension of the variables and leads to decrease of unfeasible solutions in the iterative procedure.

To illustrate the new decision variables consider a 33-bus distribution system shown in figure, which consists of 32 sectionalizing switches and 5 tie switches. The initial tie switches are represented by dotted lines and sectionalizing switches are represented by straight lines. The basic procedure for designing new decision variables is as follows.

i) Close all of the sectionalizing switches, open all of the tie switches, and form an initial radial network.

ii) Close the first tie switch (s33)and form first independent loop ,say loop1

iii) Assume the decision variable of loop1 as x1,and number the tie switches in loop1 using consecutive integers ,for example if we number switches s2,s3,s4,s5,s6,s7,s33,s20,s19,s18 using 1,2,3,4,5,6,7,8,9,19, then possible solution set x1is set [1 10] .

Similarly other decision variables are also defined.

B. Description on Switch state

Dimension of decision variables are reduced by taking independent loops as decision variables. However, it does not avoid the cases to appear unfeasible solutions.

The switches are described in four states so as to reduce unfeasible solutions and/or further improve the efficiency of calculation.

1) Open State**:** In this state a switch is open in a feasible solution.

2) Closed State: In this state a switch is close in a feasible solution.

3) Permanent closed state: which means a switch is closed in all feasible solutions.

4) Temporary closed state: which means a switch must be closed in a feasible solution because another switch is open in the feasible solution and switch may be open or closed in another feasible solution.

A switch, which is close to source node, should be closed in any feasible solution. In Fig. 2, switches s2,s3,s18to be considered as permanent closed state and thus reduces the search space. Switches belong to same two or three independent loops are interrelated. In a feasible solution only one of the interrelated switches may be in open state ; otherwise there will appear isolated islands in the network. In Fig. 2, switches s9,s10,s11 be belong to both loop2 and 3,so they are interrelated. If the solution of x2 is the number of s9 in loop2, then the solution of x3 does not be number of s10, s11must be temporary closed state. Thus unfeasible solution is avoided by interrelation of switches.

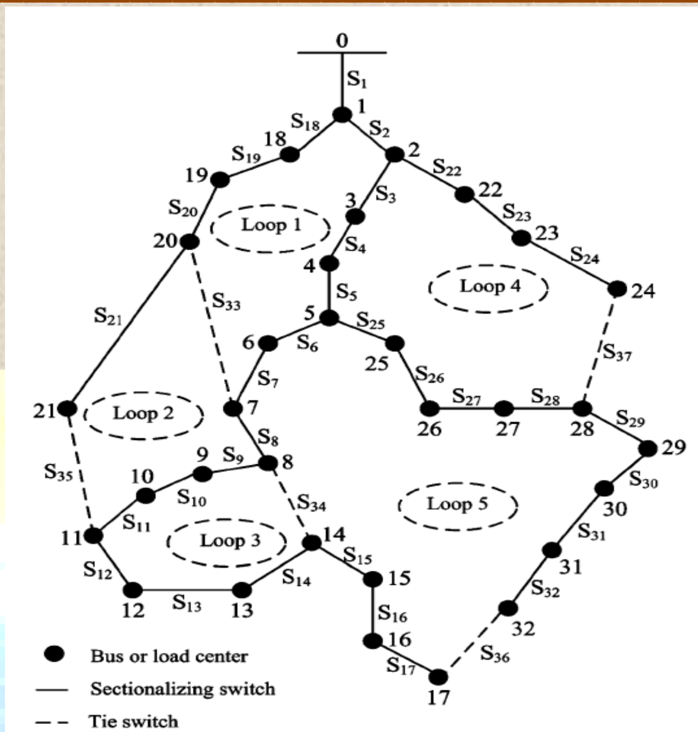

Fig. 2. The 33-bus sample system

C. Algorithm for Distribution Network Optimization

1) Read System Data

2) Let all tie switches are in open, take it has initial solution xo, which corresponds to the root of the plant

3) Run load flow for radial distribution system and calculate the initial objective function(power loss) $f(X_o)$

4) Let X_b be initial preferential growth node of a plant, and the initial value of optimization xbest equal to X_o.

5) Let iteration count N=1;

6) Search for new feasible solutions: open one branch at a time in a loop in a sequence including tie switch starting from basic point $X_b=[X_{1b},X_{2b},X_{3b},\ldots\ldots X_{nb}]$.

7) For the found every possible solution xp, carry out the check of node voltage constrains and branch power. Abandon the possible solution xp if it does not satisfy the constraints,

otherwise calculate powerloss i.e; objetive function $f(X_p)$ and compare with $f(X_o)$. Save the feasible solutions if $f(X_p)$ less than $f(X_o)$;if no single feasible solution does not satisfy $f(X_p)<f(X_o)$ go to step10

8) Calculate the probabilities $C_1, C_2, \ldots C_k$ of feasible solutions $X_1, X_2, \ldots X_k$, by using $C_k=(f(x_o)-f(x_k))/\Delta$ where $\Delta=(f(x_o)-f(x_i))$, which corresponds to determing the morphatin concentration of the nodes of a plant.

9) Calculate the accumulating probabilities $\sum C_1, \sum C_2, \ldots \sum C_k$ of the solutions x1,x2,….xk . select a random number βfrom the interval [0 1], β must belong to one of the intervals $[0\ \sum C_1]$, $(\sum C_1, \sum C_2]$, ….,$(\sum C_{k-1}, \sum C_k]$, the accumulating probability of which is equal to the upper limit of the corresponding interval,will be the new basic point for the next iteration ,which corresponds to the new preferential growth node of a plant for next step, and go to step6. $N>N_{max}$ is the stopping criteria, where N_{max} is a given allowable consecutive iteration number, the choice of N_{max} depends on the size and difficulty of the problem. if stopping criteria is satisfied go to next step, otherwise increase iteration count N and go to 6

10) Save the new feasible solution, which corresponds final solution.

The flow chart of distribution network optimization based on Plant Growth Simulation Algorithm (PGSA) is shown below. New feasible solution is obtained from the flow chart. Here objective function and constrains are taken separately.

IV. GENETIC ALGORITHM:

A. Introduction

Genetic Algorithm (GA), first introduced by John Holland in early seventies, is becoming a flagship among various techniques of machine learning and function optimization. Algorithm is a set of sequential steps needs to be executed in order to achieve a task. A GA is an algorithm with some of the principles of genetics included in it. The genetic principles “Natural Selection” and “Evolution Theory” are main guiding principles in the implementation of GA. The GA combines the adaptive nature of the natural genetics and search is carried out through randomized information exchange.

There is multitude of search techniques. Among them Calculus based, Enumerative and Random Search Techniques are mostly used. The first two techniques i.e., Calculus based and Enumerative are capable of arriving at reasonably good solutions for search spaces of smaller size and wide variation from point to point in their precinct, like all practical systems, Their efficiency is low in delivering solution for complex problems involving huge search space due to their lack of ability to overcome these local optimum points and reach the global optimum point. In order to overcome local optimum points we use random search techniques. It is important to note that this Randomized search is not a directional search. The search is carried out randomly and information gained from a search is utilized in guiding the next search. Genetic Algorithms is an example of such search technique.

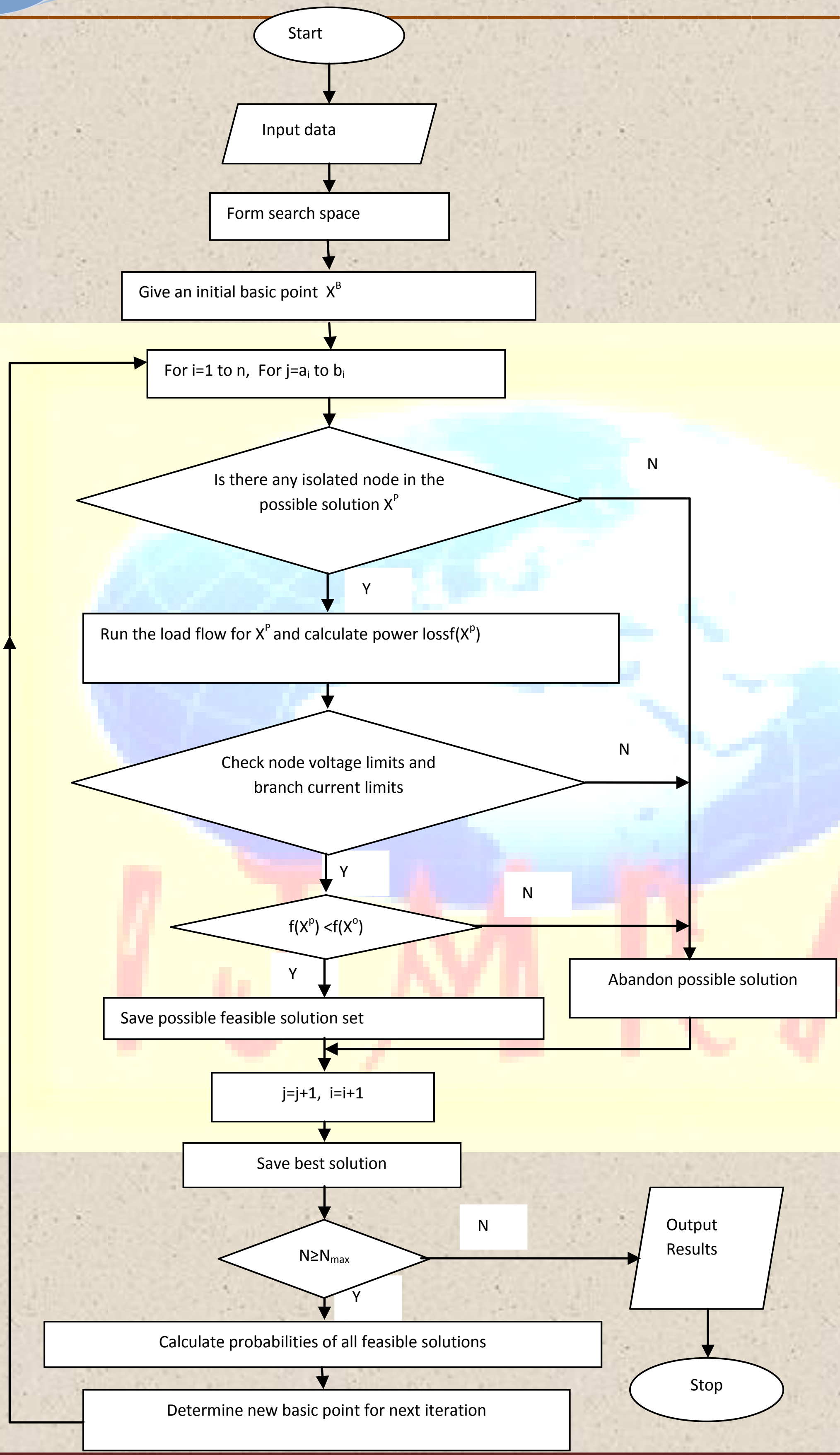
Start
Input data
Form search space
Give an initial basic point X^B
For i=1 to n, For j=a_i to b_i
Is there any isolated node in the possible solution X^P
N
Y
Run the load flow for X^P and calculate power lossf(X^P)
Check node voltage limits and branch current limits
N
Y
N
f(X^P) <f(X^o)
Y
Abandon possible solution
Save possible feasible solution set
j=j+1, i=i+1
Save best solution
N
N≥N_max
Output Results
Y
Calculate probabilities of all feasible solutions
Stop
Determine new basic point for next iteration

Fig. 3. Flow Chart for Proposed Method

Genetic Algorithms surpasses all the above limitations of conventional algorithms by using the basic building blocks that are different from those of conventional algorithms. It is different from them in the following aspects.

1. GA works with a coding of the parameter set and not the parameters themselves.

2. GA searches from a population of points and not from a single point like conventional algorithms.

3. GA uses objective function information, not derivative or other auxiliary data.

4. GA use probabilistic transition rules by stochastic operands, not deterministic rules.

TABLE 1

SIMULATION RESULTS OF SYSTEM 1

Items	Initial state	Proposed method	GA
Open switches	S33, S34, S35, S36, S37	S7, S9, S14, S37, S32	S33, S9, S34, S28, S36
Loss(kW)	202.7	139.5	140.6

V. TEST RESULTS:

System 1: The example is a 12.66-kV system, as shown in Fig. 2. It consists of 33 buses and five tie lines; the total load conditions are 3715 kW and 2300 kvar. Bef-ore net-work optimization, the open switches are S33, S34, S35, S36and S37; the closed switches are S1 to S32; the corre-sponding power losses are 202.7 kW. Selection of the allo-wable consecutive iterative number Nmax depends highly on the solved problem. Simulation results obtained by applying power genetic algorithm(GA) in which the popula-tion size, crossover rate, and mutation rate are 85, 0.8, and 0.05, respectively.

VI. CONCLUSIONS:

Plant Growth Simulation Algorithm is a new and efficient method for the network optimization of power distribution systems, where the objective is to minimize the total real power loss. The simulation results based on a 33-bus sample system and a 69-bus real system have produced the best solutions that have been found using a number of approaches available in the technical literature.

The advantages of PGSA over other approaches are:

1) The proposed approach handles the objective function and the constraints separately, avoiding the trouble to determine the barrier factors.

2) It does not require any external parameters such as crossover rate and mutation rate in genetic algorithm;

3) The proposed approach has a guiding search direction that continuously changes as the change of the objective function. Moreover, an elegant design of decision variables and a detailed description on switch state considerately improve the efficiency of calculation.

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