Improved Music Based Harmony Search algorithm for Optimal Network Reconfiguration

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Improved Music Based Harmony Search Algorithm for Optimal Network Reconfiguration

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***Abstract*— Distribution network reconfiguration is a complex combinatorial optimization process aimed at finding a radial operating structure that minimizes the system power loss, deviation of node voltages and service restoration while satisfying operating constraints. A Music Based Harmony Search algorithm (MBHS) is a recently developed algorithm which is conceptualized using the musical process of searching for a perfect state of harmony. It uses a stochastic search instead of a gradient search. In this paper, an Improved Music Based Harmony Search (IMBHS) algorithm is proposed to solve the network reconfiguration problem in order to minimize the power loss. Constant Complex Matrix Power Flow method is used to solve the radial distribution system. The proposed approach is tested on standard IEEE 33-bus system. The results are compared with MBHS algorithm and it is observed that the proposed method performed well in terms of the quality of solution.**

Keywords— distribution load flow, harmony search, loss reduction and reconfiguration.

I. INTRODUCTION

The smart distribution feeder is a foundational element of the smart grid. Optimal Network Reconfiguration (ONR) of distribution feeders has direct impact in accomplishing the smart grid characteristics. ONR identifies the ways in which an electric utility can reconfigure an interconnected set of distribution feeders to accomplish one or more specified objectives without violating any operational constraints on the feeder.

Most electric distribution feeders are configured radially for effective co-ordination of their protection systems. Distribution feeders contain a number of switches that are normally closed and switches that are normally open. Under normal operating conditions, distribution engineers periodically reconfigure distribution feeders by opening and closing the switches (switching operations) in order to increase network reliability and/or reduce line losses. The resulting feeders must remain radial and meet all load requirements.

Distribution system reconfiguration for loss reduction was first proposed by Merlin and Back [1]. They employed a blend of optimization and heuristics to determine the minimal-loss operating configuration for the distribution system represented by a spanning tree structure at a specific load condition. The strength of the algorithm is that an optimal solution can be obtained, which is independent of the initial switch status, but the shortcomings in that paper are: contribution of real component of current was considered while calculating power loss, voltage angles are assumed negligible, the losses associated with line equipment are not considered and the solution proved to be highly time-consuming as the possible system configuration is of the order 2^n, where 'n' is line sections equipped with switches.

A branch and bound type heuristic algorithm was suggested by Civanlar *et al.* [2]; a simple formula was developed for determination of change in power loss due to a branch exchange. The advantages of this algorithm are rapid determination of a switching configuration, which reduces the loss and the number of switching combinations due to heuristic rules. The disadvantages are consideration of a single pair of switching operations at a time and the reconfiguration of network depends on the initial switch status.

Power flow method-based heuristic algorithm (PFBHA) was suggested in [3]–[5] to determine the minimum loss configuration of radial distribution networks. Shirmohammadi and Hong [3] modeled the weakly meshed networks accurately by using a compensation-based power flow technique. The shortcomings of [3] are the inefficient search strategy, which is time-consuming and unbalanced multiphase distribution systems are not efficiently modeled. Wagner et al. [4] presented the reconfiguration problem as linear transportation problem and approximated the quadratic feeder line section losses as piecewise linear function. This method converges well and is efficient for small distribution systems; however, the analysis of larger networks would result in an excessive computational burden for real-time implementation. Goswami and Basu [5] proposed a method in which any switch closure is complemented by the opening of another switch to ensure a radial network. Although this method is suitable for smaller systems but it becomes prohibitive for larger networks as the solution involves a huge number of computations.

Simulated Annealing (SA) method was proposed as a solution procedure by some authors [6]–[8] to search an acceptable non-inferior solution. Although mathematically rigorous, the algorithm is very time-consuming for any practical problem. Nara et al. [9] presented a solution using a Genetic Algorithm (GA) to look for the minimum loss configuration. They formed strings, which represented switch status, a fitness function consisting of total system losses and penalty values of voltage drop limit and current capacity limit. Sample results demonstrate that although the minimal loss solutions were obtained, the solution time was prohibitive for medium size systems. Few other meta-heuristic techniques like Hybrid Evolutionary Algorithm based on Ant Colony

Optimization (ACO) and SA, Discrete Genetic Algorithm (DGA), and Ant Colony Technique are proposed by some authors[10]-[15]. Although the methods mentioned above do not have good convergence property, most of them are used due to less computation time requirement for smaller systems.

For larger systems, the computation time is prohibitively high and may not be suitable for real-time operation. Srinivasa et al. [16] proposed a Harmony Search algorithm for network reconfiguration of large scale distribution systems and proved that Music Based Harmony Search method can more efficiently search the optimal or near-optimal solution for network reconfiguration problems. In this paper an Improved Music Based Harmony Search (IMBHS) method is proposed for optimal feeder reconfiguration of large scale distribution systems and a Constant Complex Matrix Power Flow Model is used to find the power flow and power loss in distribution system in order to reduce the computation time.

II. PROBLEM FORMULATION

A. Objective functions:

To find the best switching candidates for distribution system reconfiguration, it is necessary to define the optimality of each possible switching operation. In this paper the objective function is to minimize the real power loss.

1) Power loss reduction:

Minimizing the real power loss of feeder is selected as the main objective function for feeder reconfiguration problem. The power loss of a distribution system is calculated as:

$$P_{loss} = \sum_{i=1}^{nl} I_i^2 R_i \tag{1}$$

where, *'I_i' and 'R_i'* are the current and resistance of circuit branch *'i'*; *'nl'* is the number of circuit branches. A low P_{loss} value indicates economic operation of a network.

2) Operation constraints:

To provide quality electrical supply, the voltage magnitude at each bus after the switching operation must be within a permissible range and the current loading of distribution feeders must be within the rated limits. These constraints are expressed as $V_{min} \le V \le V_{max}$ and $|I| \le I_{max}$; where V_{min} and V_{max} are the lower and upper limits of bus voltage. The current rating I_{max} of the feeder is determined by the conductor size.

In addition to the above electrical constraints which have to be identified and satisfied, no feeder section must be left out of service and the radial network structure must be maintained.

B. Constant Complex Matrix Power Flow Model

In the network, the net injected active and reactive powers at an i^{th} bus are given by

$$P_i = V_i \sum_{j=1}^{nb} V_j \left[G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}\right] \tag{2}$$

$$Q_i = V_i \sum_{j=1}^{nb} V_j \left[G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}\right] \tag{3}$$

where, V_i, V_j are the voltage magnitudes at i^{th} and j^{th} buses respectively and $\theta ij=\theta i-\theta j$; θi , θj are the bus angles of i^{th} and j^{th} buses respectively. $G_{ij} + jB_{ij}$ represents the ij^{th} element of Y-bus and *nb* is the total number of buses.

The linearized power flow equations of (2) and (3) are expressed in compact form as

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J1 & J3 \\ J2 & J4 \end{bmatrix} \begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} \tag{4}$$

$$\text{where} \quad \Delta P_i = P_{scheduled,i} - P_{calculated,i} \tag{5}$$

$$\text{and} \quad \Delta Q_i = Q_{scheduled,i} - Q_{calculated,i} \tag{6}$$

[$\Delta\theta$] and [ΔV] are the corrections vectors for busbar angles and busbar voltages.

The assumptions considered for forming a constant complex matrix[17] are

- All network shunt reactances such as line charging reactances, external reactances located at buses and shunts formed due to π representation of off-nominal in-phase transformers are lumped at each bus are treated as constant impedance loads.
- All bus voltages are assumed to be of $1.0\angle 0^\circ$ at the beginning of the iterative process.

With these assumptions, equation (4) takes the form as

$$\begin{bmatrix} \Delta P' \\ -\Delta Q' \end{bmatrix} = \begin{bmatrix} -B & G \\ G & B \end{bmatrix} \begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} \tag{7}$$

where, $\Delta P'$ and $\Delta Q'$ are same as in equations (5) and (6).

The equation (12) can be written in complex form as

$$\begin{gathered} \left[\Delta P' - j\Delta Q'\right] = \left[J\right]\left[\Delta V + j\Delta\theta\right] \\ where, \left[J\right] = \left[G + jB\right] \end{gathered} \tag{8}$$

The Jacobian is Y-Bus devoid of shunts (excluding the substation bus row and column). The order of the Jacobian is [(*nb-1*) x (*nb-1*)]. The [*J*] is in complex form and this is triangularized at the beginning of the power flow solution and kept constant throughout the solution.

C. Improved Music Based Harmony Search Algorithm (IMBHS)

IMBHS employs a novel method for generating new solution vectors that enhances accuracy and convergence rate of Music Based Harmony Search (MBHS) algorithm. A brief overview of the MBHS and its modified procedure algorithm is presented herewith.

1) Music Based Harmony Search (MBHS) algorithm:

A MBHS algorithm was developed as an analogy with music improvisation process where music players improvise the pitches of their instruments to obtain better harmony [18]. The steps in the procedure of Harmony Search (HS) are:

Step 1: Initialize the problem and algorithm parameters.
Step 2: Initialize the harmony memory.
Step 3: Improvise a new harmony.
Step 4: Update the harmony memory.
Step 5: Check the stopping criterion.

Step1: Initialize the problem and algorithm parameters

Consider an optimization problem which is described as: Minimize,

$$F(x) \text{ subject to } x_i \in X_i,\ i=1,2,3,\ldots..N. \qquad (9)$$

where, *F(x)* is objective function, '*x'* is a set of each design variable (x_i), 'X_i' is set of the possible range of values for each design variable ($Lx_i < X_i < Ux_i$), and '*N'* is the number of design variables.

The HS parameters are specified in this step. These are Harmony Memory Size (HMS), or number of solution vectors in the harmony memory; Harmony Memory Considering Rate (HMCR); Pitch Adjusting Rate (PAR); and Number of Improvisations (NI) or stopping criterion. The Harmony Memory (HM) is a memory location where all the solution vectors (sets of decision variables) are stored. The parameters *HMCR* and *PAR* are used to improve the solution vector and these are defined in step 3.

Step2: Initialize the harmony memory

In this step, the HM matrix is filled with as many randomly generated solution vectors as the HMS:

$$HM = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_{N-1}^1 & x_N^1 \\ x_1^2 & x_2^2 & \cdots & x_{N-1}^2 & x_N^2 \\ \vdots & \vdots & & \vdots & \vdots \\ x_1^{HMS-1} & x_2^{HMS-1} & \cdots & x_{N-1}^{HMS-1} & x_N^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & \cdots & x_{N-1}^{HMS} & x_N^{HMS} \end{bmatrix} \begin{matrix} \Rightarrow f(x^{(1)}) \\ \Rightarrow f(x^{(2)}) \\ \vdots \\ \Rightarrow f(x^{(HMS-1)}) \\ \Rightarrow f(x^{(HMS)}) \end{matrix} \qquad (10)$$

Step3: Improvise a new harmony from the HM set

A new harmony vector, $x' = (x_1', x_2', \ldots, x_n')$, is generated based on three rules, namely, random selection, memory consideration and pitch adjustment.

These rules are described as follows:

- *Random Selection:* When HS determines the value, x_i' for the new harmony, $x' = (x_1', x_2', \ldots, x_n')$, it randomly picks any value from the total value range with a probability of (1-HMCR). Random selection is also used for previous memory initialization.
- *Memory Consideration:* When MBHS determines the value x_i', it randomly picks any value x_i^j from the HM with a probability of HMCR since $j = \{1,2,\ldots, \text{HMS}\}$.

$$x'_i \leftarrow \begin{Bmatrix} x'_i \in \{x_i^1, x_i^2, \ldots\ldots, x_i^{HMS}\} & \text{with probability } HMCR \\ x'_i \in X_i & \text{with probability } (1\text{-}HMCR) \end{Bmatrix} \qquad (11)$$

- *Pitch Adjustment:* Every component of the new harmony vector, $x' = (x_1', x_2', \ldots, x_n')$, is examined to determine whether it should be pitch-adjusted. After the value x_i' is randomly picked from HM in the above memory consideration process, it can be further adjusted into neighboring values by adding certain amount to the value, with probability of PAR.

This operation uses the PAR parameter, which is the rate of pitch adjustment given as follows:

$$x'_i \leftarrow \begin{Bmatrix} Yes & \text{with probability } PAR \\ No & \text{with probability } (1\text{-}PAR) \end{Bmatrix} \qquad (12)$$

The value of (1-PAR) sets the rate of doing nothing. If the pitch adjustment decision for x_i' is yes, x_i' is replaced as follows:

$$x'_i \leftarrow x'_i \pm bw \qquad (13)$$

where, '*bw'* is the arbitrary distance bandwidth for a continuous design variable.

In this step, pitch adjustment or random selection is applied to each variable of the New Harmony vector.

Step 4: Updating HM

If the new harmony vector, $x' = (x_1', x_2', \ldots, x'_n)$, is better than the worst harmony in the HM, from the viewpoint of the objective function value, the new harmony is entered in the HM and the existing worst harmony is omitted from the HM [18].

Step 5: Checking stopping criterion

Computation is terminated upon satisfying the maximum number of improvisations or maximum number of iterations, which is the stopping criterion. Otherwise, steps 3 and 4 are repeated.

2) Improved Harmony Search Algorithm

The traditional MBHS algorithm uses fixed value for both *PAR* and *bw*. The *PAR* and *bw* values adjusted in the initialization step (Step 1) cannot be changed during new generations. The main drawback of this method is that this employs higher number of iterations to converge at an optimal solution.

Small *PAR* values with large *bw* values can lead to poor performance of the algorithm and considerable increase in the number of iterations to find optimum solution. Small *bw* values in the final generations increase the fine tuning of solution vectors. Therefore, large *PAR* values with small *bw* values usually leads to improvement in obtaining the best solution in the final generation in which the algorithm converges to optimal solution vector [19]. The IMBHS has been developed by Madhavi et al. [20] and has been successfully applied to various benchmarking and standard engineering optimization problems. Numerical results proved that the improved algorithm can result in better solutions when compared to the conventional MBHS and other heuristic or deterministic methods.

The key difference between IMBHS and traditional MBHS method is in the way of adjusting *PAR* and *bw*. To improve the performance of the MBHS algorithm and eliminate the drawbacks associated with the fixed values of *PAR* and *bw*, the IMBHS algorithm uses variable *PAR* and *bw* in the improvisation step (Step 3).

The *PAR* values change dynamically with generation number as shown in Fig. 1 and expressed as follows [20]:

$$PAR(gn) = PAR_{\min} + \left(\frac{PAR_{\max} - PAR_{\min}}{NI} \right) \times gn \qquad (14)$$

where, *PAR* is the pitch adjusting rate for each generation, PAR_{min} is the minimum pitch adjusting rate, PAR_{max} is the maximum pitch adjusting rate, *NI* is the number of solution vector generations and *gn* is the generation number.

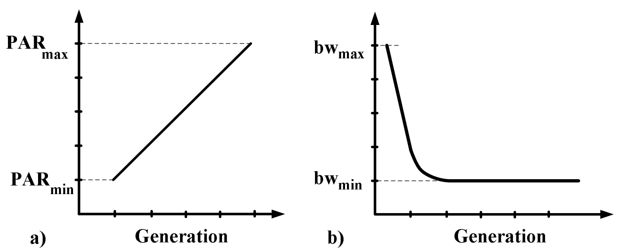

Figure 1: a) Variation of PAR versus generation number, b) Variation of *bw* versus generation number.

Bandwidth *(bw)* changes dynamically with generation number as shown in Fig. 1 and defined as follows:

$$bw(gn) = bw_{\max} \ \exp(c.gn) \qquad (15)$$

$$C = \frac{Ln\left(\frac{bw_{\max}}{bw_{\min}} \right)}{NI} \qquad (16)$$

where, *bw(gn)* is the bandwidth at each generation, bw_{min} and bw_{max} are the minimum and the maximum bandwidths respectively.

III. METHODOLOGY

The optimal distribution network is obtained by first generating all possible radial structures of the given network without violating the constraints and subsequently evaluating the objective function.

Conventional optimization methods are ineffective and impractical because, the real distribution system contains many nodes and branches.

An IEEE 33-bus system [3] as shown in fig 2 is considered for the proposed algorithm. The IEEE 33-bus system, 12.66kV, radial distribution system consists of 32 lines, 5 tie-line and all these lines and tie-lines are considered as switches.

For the reconfiguration of the system, any switch can be opened or closed without forming any loops and providing service to all the loads. For closing of each tie-switch one loop is formed. If all the tie switches are closed, a total of 5 loops are formed. In order to maintain the radial structure one switch is opened from each loop without isolating any node and without forming islands. Loop vectors formed in IEEE 33-bus system upon closure of the tie-switches are given in table I.

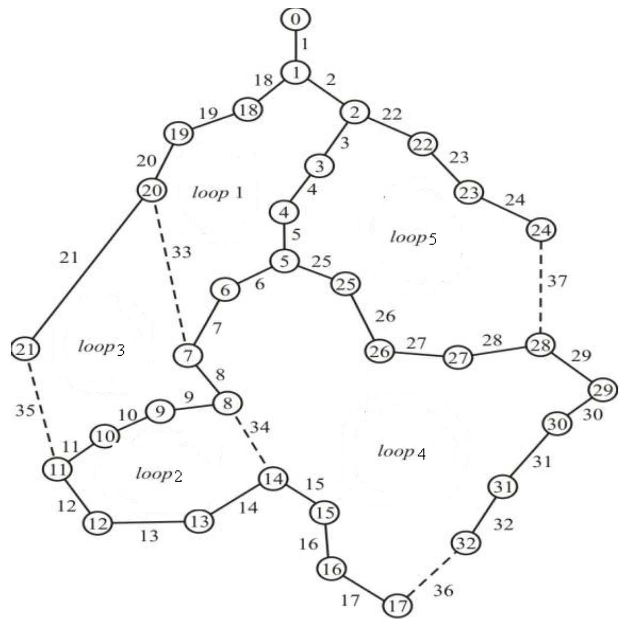

Figure 2. IEEE 33-BUS SYSTEM

TABLE I. LOOP VECTORS FORMED BY EACH TIE LINE

Tie Line	Loop Vector
Loop1 33	2, 3, 4, 5, 6, 7, 18, 19, 20
Loop2 34	9, 10, 11, 12, 13, 14
Loop3 35	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 18, 19, 20, 21
Loop4 36	6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 25, 26, 27, 28, 29, 30, 31, 32
Loop5 37	3, 4, 5, 22, 23, 24, 25, 26, 27, 28

Generally, solution vector consists of two strings or two parts; the former containing all closed switches and the latter containing the open switches. The length of the string is given by the summation of the number of lines and tie-lines. For large distribution system the length of string is very long. In this method, memorization is confined to only open switches. Here the IEEE 33-bus system has 5 tie-switches (normally open switches). Then the length of the solution vector is same as number of tie-switches, which is 5. The solution vector of the original configuration is HM1= [33 34 35 36 37].

Similarly other possible solution vectors are generated without violating the constraints. All five switches are selected from five different loops and five different switches have to be selected. Evaluate the objective function *i.e.* power losses if the solution generated is feasible (solution is feasible means system is radial and service is provided for all the loads) otherwise generate another solution. Parameters of IMBHS algorithm are given below.

TABLE II. PARAMETERS OF IMBHS

HMS	10
HMCR	0.85
PAR_{min}	0.4
PAR_{max}	0.99
BW_{min}	0.0001

BW_{max}	1
NI	20
No.of iterations	50

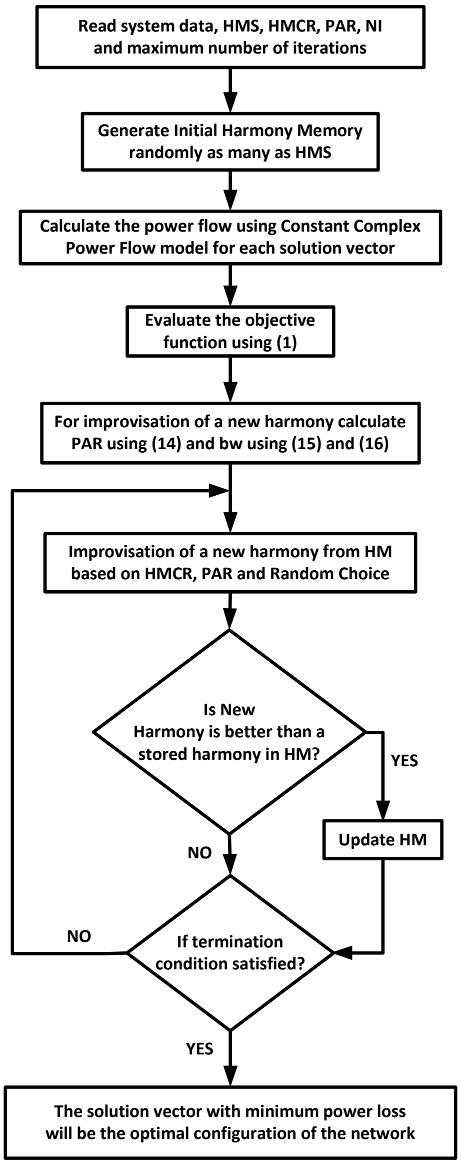

Fig 3: Flowchart of IMBHS algorithm

IV. RESULTS AND DISCUSSION

The proposed method is tested on IEEE 33bus distribution system and the results obtained to demonstrate the effectiveness of the IMBHS when used for loss minimization via feeder reconfiguration. The assumptions made while using the test system is that every branch has a sectionalizing switch such that it can be opened and closed whenever required and the substation voltage is considered as 1 p.u.

The algorithm was developed in MATLAB, and the simulations were done on a computer with Pentium Dual Core, 1.7GHz, 1GB RAM. For the IEEE 33 bus distribution system the total real and reactive power loads on the system are 3715 kW and 2300 kVAr, respectively. The initial power loss of this system is 202.771 kW. The lowest bus bar voltage is 0.9131 p.u., occurs at node 18.

The parameters of IMBHS algorithm used in simulation are given in the table.II. The optimal reconfiguration obtained by using proposed algorithm for IEEE 33 bus system is 7,9,14,32,37 which has a real power loss of 139.55kW and the minimum bus voltage is 0.95 at IEEE 33 bus after reconfiguration. The loss is reduced by 31.148%.

Table III: Results of IEEE 33 bus system

	Initial configu -ration	*Final Configuration*				
		GA [9]	**ITS [10]**	**ACA [11]**	**MBHS [16]**	**Propose d Method IMBHS A**
Tie Switches	**33,34, 35, 36,37**	**7,11,14, 28,32**	**7,9,14, 37,36**	**7,9,14, 32,37**	**7,10,14, 36,37**	**7,9,14,32, 37**
Power Loss (kW)	**202.71**	**141.6**	**142.17**	**139.55**	**142.68**	**139.55**
Loss Reduction (%)	**-**	**30.15**	**29.87**	**31.16**	**29.61**	**31.16**
Minimum Voltage (p.u)	**0.9131**	**0.9290**	**-**	**0.9375**	**-**	**0.9375**
CPU Time(s)	**-**	**19.1**	**8.1**	**-**	**7.2**	**5.1**

From Table. III, it is observed that optimal power loss obtained by proposed method is best solution when compared to other methods GA, ITS and MBHSA and same as ACA.

The best optimal solution is obtained in 15 iterations but, for the comparison purpose simulations are carried out for 250 iterations. The average CPU time taken by the processor to carry out the simulations for 250 iterations is 5.1 s, which is less than all the other methods.

V. CONCLUSION

An Improved Music Based Harmony Search algorithm is proposed for the feeder reconfiguration of a radial distribution network.

Constant Complex Matrix Power Flow Model is used to evaluate the power flow of the given network, which reduces the computation time.

From the test results, it is inferred that the real power losses are reduced significantly and overall voltage profile of the network is improved considerably.

IMBHS takes lesser number of iterations in order to reach optimal solution when compared all other methods like to MBHS, GA, RGA and ITS. Because of less computation time, proposed method is very use-full in case of emergency service restoration problems.

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