PARTICLE SWARM OPTIMIZATION BASED APPROACH FOR LOSS REDUCTION IN UNBALANCED RADIAL DISTRIBUTION SYSTEM

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Abstract:

The losses at distribution level contribute a major portion of power system losses. Proper sizes of shunt capacitors in unbalanced radial distribution systems (URDS) can reduce some portion of this loss and can improve the voltage profile of the feeder section. Most conventional optimization techniques are in capable to solve this hard combinatorial problem with set of operating conditions where as particle swarm optimization (PSO) algorithm is very suitable. This paper presents an efficient algorithm for determining the location, type and size of capacitor bank to be installed in unbalanced radial distribution system. The main objective function formulated consists of two terms: Cost of energy loss and cost related to capacitor purchase and capacitor installation, so that the fitness function is to be maximizing for the net saving.

Keywords: Power Loss Indices, Capacitor banks, Loss Minimization, Unbalanced Radial Distribution Systems, Particle Swarm Optimization.

1.0 Introduction

There are several methods have been proposed [Abdul-Salam, et.al,(1994), Baran, M.E ;et al,(1989)] to analyze this Capacitor placement problem in the past in the area of reactive power compensation for radial distribution networks. [Bridenbaugh, C. J; Di Mascio,et al,(1992)] Voltage improvement through capacitor and Capacitor optimization is analyzed.[Sundhararajan and Pahwa et al,(1994)] used genetic algorithm for obtaining the optimum values of shunt capacitors. They have treated the capacitors as constant reactive power load. [T.S.Abdul salma et al,(1994)] proposed a heuristic technique, which brings about the identification of the sensitive buses that have a very large impact on reducing the losses in the distribution systems. [C.S.Chen et al,(1995)] developed a systematic method of optimally locating and sizing of the shunt capacitors compensation on distribution feeders by taking into account the mutual coupling effect among phase conductors. The capacitor placement and sizing problem is a nonlinear integer optimization problem, with locations and ratings of shunt capacitors being discrete values. Series capacitors and shunt capacitors [Carlise, J.C.; El-Keib et al,(2000):] are widely used in distribution systems due to various limitations in the usage. Mainly capacitors are used to develop reactive power near the point of consumption. Shunt capacitors are commonly used in distribution systems for reactive power compensation for several reasons, in particular in order to reduce power losses, to improve the voltage profile [Das, D; Kothari et al,(1995)] along the feeders and to increase the maximum power flow through cables and transformers. The proposed method was demonstrated both the balanced and unbalanced systems. [S.K. Goswami et al,(1999)] developed heuristic rules for the determination of the most sensitive capacitor placement problem. Using these rules, a technique was developed to identify a number of probable capacitor locations in a distribution network [H. Kim and S.K You et al,[1999] used genetic algorithm for obtaining the optimum values of shunt capacitor bank. They have treated the capacitors as constant reactive power loads. [Mady, IB et.al,(2009)] proposed optimal sizing of capacitor banks and distributed generation in distorted distribution networks by genetic algorithms. [Eajal,A. et.al,[2010] a technique was developed for optimal capacitor placement and sizing in unbalanced distribution systems with harmonics consideration using particle swarm optimization.

In this Paper, power loss indices (PLI) analysis used for capacitor placement problem and also presents a candidate bus identification method to determine the best locations for Optimal capacitor placement. The PSO based approach is used to find the optimal sizing of the capacitor bank in unbalanced radial distribution systems.

2.0 Mathematical Formulation

The objective function formulated includes the energy cost, capacitor installation cost and purchase cost, so that the fitness function is to be maximized for the net savings function (f) by placing the optimal size of the capacitor. The objective function can be expressed as:

$$Maximize \quad f = \left\{ EC \times \left[\sum_{j=1}^{nb} P_{loss\ j}^{\ abc} - \sum_{j=1}^{nb} P_{loss\ j}^{\ abc'} \right] \times T - a \times \left[IC \times nc + \sum_{j=1}^{nc} CC \times CB \right] \right. \qquad (1)$$

Where,

EC is energy Cost in Rs/kWh

T is time Period in hours

$P_{loss\ j}^{abc}$ is the total active power loss before capacitor placement

$P_{loss\ j}^{abc'}$ is the total active power loss after capacitor placement

a is the depreciation factor

IC is the installation cost

nc is the number of capacitor buses

CC is the cost of the three phase capacitor

CB_i^{abc} is the capacitor bank rating in kVAr

3.0 Candidate Buses for the placement of Capacitors

The proposed candidate bus identification method for capacitor placement is explained with 25 bus URDS whose single line diagram is shown in Fig 2. The line and the load data of this system are given in [20]. After performing the base case load flows, total active power loss of system is 150.1225 kW.

After compensating the reactive power injection at each bus in all the phases equal to local reactive load of the system at that particular bus, perform the load flows as explained in [5] and record the total active power loss and loss reduction of the system. This procedure is repeated for all remaining buses except source bus.

The power loss indices (PLI) are calculated as

$$\text{PLI[i]} = \frac{(Loss.reduction[i] - Min.reduction)}{(Max.reduction - Min.reduction)} \qquad (2)$$

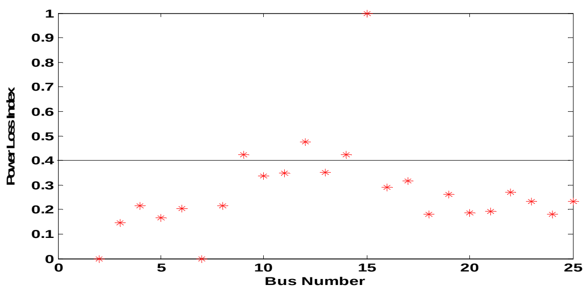

Fig.1 Plot between bus number and Power Loss Index

The most suitable buses for the capacitor placement are chosen based on the condition that PLI must be greater than PLI tolerance value should be lies in between '0' and '1'. The tolerance value for a chosen system is selected by experimenting with different values in descending order of the PLI limits. The best value of the tolerance value gives the highest profit and satisfies the system constraints. Fig.1 shows power loss index Vs bus number for 25 bus URDS. From experimentation the best value of PLI tolerance is set as 0.4. It is concluded that buses **9,12,14,15** are the best candidate uses for the capacitor placement. Assume capacitor at candidate uses with size varying the integer steps of the standard size capacitors (50 kVAr per phase).

3.1 Candidate bus identification algorithm

The algorithm of identifying the candidate buses for best suitable for capacitor placement is explained in given below:

Step 1: Read the data for a given unbalanced radial distribution system (URDS).
Step 2: Perform the load flows and calculate the base case total active power loss.
Step 3: Compensating the reactive power injections (Q_c^{abc}) at each bus (except source bus) in all the phases, run the load flow and calculate the active power loss in each case.
Step 4: Calculate the real power loss reduction and power loss indices using the following equation

$$PLI(i) = \frac{\left(X(i) - Y\right)}{\left(Z - Y\right)},\ i = 2,3,.....n. \qquad (3)$$

Where

X(i) = Loss reduction in i^{th} bus;
Y = Minimum reduction;
Z = Maximum reduction;

Step 5: Select the candidate bus whose PLI >PLI tolerance.
Step 6: Stop.

4.0 Implementation of PSO

(i). Initialization of PSO Parameters

Particle swam optimization is a population basic stochastic optimization technique developed by Dr.Eberhart and D.V Kennady in spite by social behavior of bird flocking or fish schooling in 1995. Initialize the PSO parameters like Swarm size(P), number of generations(NG), Initial weight of the weighting function (W_{max}), Final weight of the weighting function (W_{min}), weighting factors(C_1,C_2), input system data, control parameters such as lower and upper bounds of bus voltage and maximum number of capacitor banks to be installed at a compensation node. Randomly generate an initial swarm (array) of particles with random positions and velocities.

(ii). Evaluation of Fitness Function

The fitness function should be capable of reflecting the objective and directing the search towards optimal solution. The system is initialize with a population of random solutions and search for optima by updating generations. Since the PSO proceeds in the direction of evolving best-fit particles and the fitness value is the only information available to the PSO, the performance of the algorithm is highly sensitive to the fitness values. For each particle or swarm, the calculated capacitors are placed at the sensitive nodes and the load flow method is run and the losses, net savings are calculated using Eqn.(1) and these net savings becomes the fitness function of the PSO (as savings are maximized).

(iii). Optimal Solution

Particle position is updated by adding velocity to its iterative process continued till hundred iterations. So n=100. The advantage of PSO is easy to implement and there are few parameters to adjust optimal solution gives the best position and the corresponding fitness value to the target problem. Information of the best position includes the optimal locations and numbers of capacitor banks at each load level, and the corresponding fitness value represents the maximizing the total savings of the system.

This modification can be represented by the concept of velocity (modified value for the current positions). Velocity of each particle can be modified by the following equation

$$V_i^{k+1} = WV_i^k + C_1 rand_1 \times [Pbest_i - X_i^k] + C_2 rand_2 \times [Gbest - X_i^k] \qquad (4)$$

where,
V_i^k : Velocity of particle i at iteration k,
V_i^{k+1} : Modified velocity of particle i at iteration k+1,
W : Inertia weight,
C_1,C_2 : Acceleration Constants,
$rand_1$,$rand_2$: Two random numbers
X_i^k : Current position of particle i at iteration k,

$Pbest_i$: Pbest of particle i,
Gbest : Gbest of the group.

In the equation (4),

The term $rand_1 \times (Pbest_i - X_i^k)$ is called particle memory influence

The term $rand_2 \times (Gbest - X_i^k)$ is called swarm influence. The $rand_1$, $rand_2$ are the two random numbers with uniform distribution with range of { 0.0 to 1.0 }W is the inertia weight which shows the effect of previous velocity vector on the new vector. A larger inertia weight 'W' facilitates global exploration, while smaller inertia weight 'W' tends to facilitates local exploration to fine tune.The following inertia weight is usually utilized in equation (4):

$$W = W_{max} - \frac{W_{max} - W_{min}}{iter_{max}} \times iter \tag{5}$$

where,

W_{max} : initial value of the Inertia weight,
W_{min} : final value of the Inertia weight,
$iter_{max}$: maximum iteration number,
iter : current iteration number.

Accordingly, the optimal types and sizes of capacitors to be placed at each compensation node can be determined: if capacitor bank number during all load levels are identical, then the capacitor at this node can be regarded as the fixed type; if bank numbers at different load levels are not all the same, then the capacitor at this node is of switched type. The size of capacitor banks placed at each compensation node is the product of the maximum bank number and the standard size per bank.

(iv) Algorithm for Optimal Location and Size of the Capacitor

The detailed algorithm to determine optimal location and size of the capacitor is given below.

Step 1: Read system data such as Line data and Load data of the Distribution system.
Step 2: Initialize the PSO parameters such as Swarm size(P), initial weight & final weight of the weighting function (W_{max} & W_{min}), weighting factor(C_j), number of generations (NG).
Step 3: Obtain the optimal location of capacitor by using PLI(Power Loss Indices) as input.
Step 4: Randomly create initial particles where each particle is a solution to the optimal location and size of the capacitor problem.
Step 5: Initialize the velocities for the particles.
Step 6: Run the load flow for each particle and Compute the value of voltages, total active and reactive power losses at all the nodes.
Step 7: Set the local best values for each particle and global best value for the current iteration.
Step 8: Update the particle positions & velocity using eqns (4) & (5).
Step 9: If the particle position is out of boundary then it is brought back to its nearest boundary value using eqns (5).
Step 10: Execute steps 6-9 in a loop for maximum number of generations (NG).
Step 11: Stop the execution and display the global best values as the final result of optimal size of the capacitor.

5.0 Results and Discussion

The proposed algorithm is also tested on IEEE 37 bus URDS as shown in Fig.2 whereas voltage regulator has been removed from the original network. Three wire delta operating at a nominal voltage level of the test network is 4.8 kV. All line segments are undergrounded. All loads are spot loads and consist of constant power, constant current and constant impedance.The line and the load data are taken from unbalanced radial distribution test feeder [Subramnyam, J.B.V et al (2009)]. The existing load at each bus is overloaded by 25% in each phase to observe the effectiveness of the proposed method. The capacitor bank considered here is delta connected. After compensating the reactive power injection at each bus in all the phases performs the load flows and records the total active power loss, loss reduction and power loss indices in each case are given in table 3. Fig.3 shows power loss indices for 37 bus URDS. From experimentation shows that the best value of PLI tolerance is set as 0.6. It is concluded that buses **701, 737, 738, 722, 712** are the best candidate buses for the capacitor placement.

Voltage values and summary of test results of 37 bus URDS before and after capacitor placement are given in tables 2 and 3. From the results of PSO the size of the capacitor banks obtained at buses 701, 737, 738, 722 and

712 are 300, 300, 450, 600 and 150 kVAr respectively. From table 3, it has been observed that the minimum voltages in phases A, B and C are improved from 0.9497, 0.9578 and 0.9445 p.u. to 0.9622, 0.9712 and 0.9598 p.u respectively and total active power loss in each phase of A, B and C is reduced from 31.56, 23.67 and 30.44 to 25.47, 20.41 and 24.99 kW respectively after installing the capacitor banks. Hence, there is an improvement in the minimum voltage and reduction in power loss after installing the capacitor bank. The net saving Vs generation number of 37 bus URDS after capacitor placement is shown in Fig.4. Single line diagram of 37 bus URDS after capacitor placement at their candidate buses are shown in Fig.5.

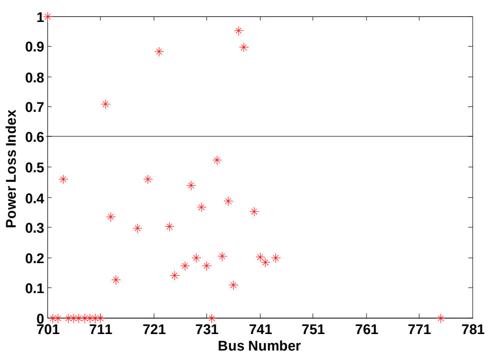

Fig.3 Plot between bus number and PLI

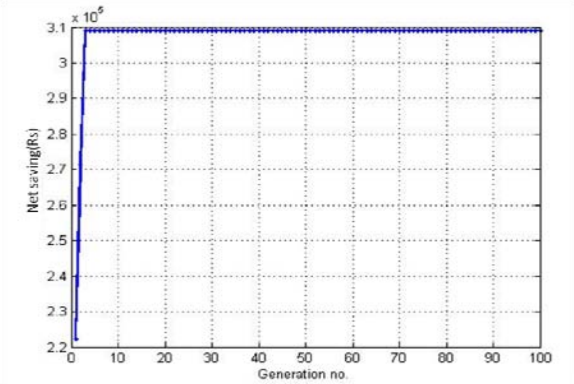

Fig.4 Net saving Vs Generation Number of 37 bus URDS

Table 1 : Power loss reductions and power loss indices for 37 bus URDS

Bus no.	Total active power loss of the system after compensating Qc at each bus (in all the phases) (kW)	Loss reduction (kW)	Power Loss Indices(PLI)
701	139.1192	10.0128	1.0000
702	149.1319	0	0
703	149.1319	0	0
730	145.4629	3.6691	0.3664
709	149.1319	0	0
708	149.1319	0	0
733	143.8993	5.2327	0.5226
734	147.0653	2.0666	0.2064
737	139.5848	9.5471	0.9535
738	140.1399	8.9921	0.8981
711	149.1319	0	0
741	147.1058	2.0261	0.2024
713	145.7922	3.3398	0.3336
704	144.5636	4.5683	0.4563
720	144.5793	4.5526	0.4547
706	149.1319	0	0
725	147.7126	1.4194	0.1418
705	149.1319	0	0
742	147.2700	1.8619	0.1860
727	147.4091	1.7228	0.1721
744	147.1512	1.9807	0.1978
729	147.1514	1.9806	0.1978
775	149.1319	0	0
731	147.3530	1.7789	0.1777
732	149.1319	0	0

710	149.1319	0	0
735	145.2422	3.8897	0.3885
740	145.5763	3.5556	0.3551
714	147.8824	1.2495	0.1248
718	146.1851	2.9468	0.2943
707	149.1319	0	0
722	140.1873	8.9446	0.8933
724	146.0963	3.0356	0.3032
728	144.7215	4.4105	0.4405
736	148.0144	1.1176	0.1116
712	142.0570	7.0749	0.7066

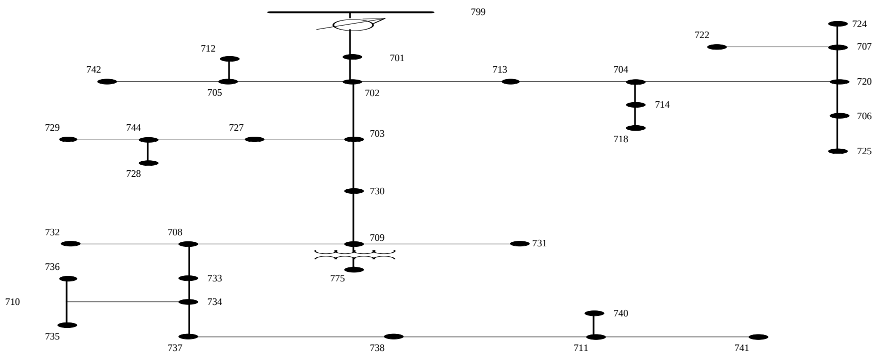

Fig.2 Single line diagram of IEEE 37 node URDS

Table 2: Voltage values of 37 bus URDS for capacitor placement

Bus No.	**Without compensation**			**With compensation PSO**		
	$\|V_a\|$(p.u)	**$\|V_b\|$(p.u)**	**$\|V_c\|$(p.u)**	**$\|V_a\|$(p.u)**	**$\|V_b\|$(p.u)**	**$\|V_c\|$(p.u)**
799	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
701	0.9863	0.9855	0.9817	0.9896	0.9898	0.9857
702	0.9781	0.9772	0.9719	0.9839	0.9844	0.9790
703	0.9709	0.9715	0.9645	0.9787	0.9811	0.9741
730	0.9652	0.9667	0.9588	0.9744	0.9777	0.9699
709	0.9634	0.9651	0.9571	0.9730	0.9766	0.9688
708	0.9607	0.9631	0.9547	0.9710	0.9753	0.9673
733	0.9582	0.9621	0.9527	0.9689	0.9747	0.9657
734	0.9547	0.9606	0.9494	0.9660	0.9739	0.9632
737	0.9512	0.9596	0.9472	0.9633	0.9737	0.9619
738	0.9501	0.9592	0.9461	0.9626	0.9737	0.9613
711	0.9498	0.9590	0.9451	0.9623	0.9735	0.9604
741	0.9497	0.9589	0.9448	0.9622	0.9735	0.9600
713	0.9763	0.9749	0.9697	0.9825	0.9826	0.9772
704	0.9740	0.9718	0.9672	0.9807	0.9800	0.9755
720	0.9727	0.9683	0.9647	0.9804	0.9775	0.9740
706	0.9726	0.9679	0.9646	0.9803	0.9771	0.9739
725	0.9725	0.9675	0.9645	0.9801	0.9768	0.9738
705	0.9761	0.9746	0.9701	0.9821	0.9821	0.9774
742	0.9757	0.9738	0.9699	0.9818	0.9813	0.9772
727	0.9697	0.9709	0.9635	0.9775	0.9805	0.9731

744	0.9690	0.9705	0.9631	0.9768	0.9801	0.9726
729	0.9686	0.9704	0.9630	0.9764	0.9800	0.9725
775	0.9634	0.9651	0.9571	0.9730	0.9766	0.9688
731	0.9632	0.9642	0.9569	0.9728	0.9757	0.9686
732	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
710	0.9542	0.9595	0.9478	0.9655	0.9728	0.9616
735	0.9541	0.9593	0.9473	0.9654	0.9727	0.9611
740	0.9497	0.9588	0.9445	0.9622	0.9734	0.9598
714	0.9737	0.9717	0.9671	0.9805	0.9799	0.9754
718	0.9723	0.9714	0.9667	0.9791	0.9797	0.9750
707	0.9709	0.9629	0.9631	0.9796	0.9734	0.9737
722	0.9707	0.9624	0.9629	0.9796	0.9730	0.9737
724	0.9705	0.9619	0.9629	0.9793	0.9724	0.9735
728	0.9686	0.9701	0.9627	0.9764	0.9797	0.9722
736	0.9536	0.9578	0.9475	0.9650	0.9712	0.9613
712	0.9751	0.9737	0.9691	0.9813	0.9814	0.9766
Min.Voltage	0.9497	0.9578	0.9445	0.9622	0.9712	0.9598

Table 3: Summary of test results of 37 bus URDS for capacitor placement

Description		**Without Compensation**			**With Compensation**					
					Existing method[15]			**Proposed method**		
	Node no.	**Phase A**	**Phase B**	**Phase C**	**Phase A**	**Phase B**	**Phase C**	**Phase A**	**Phase B**	**Phase C**
Size of the Capacitor(Qc in kVAr) with node number	701	---	---	---	100	100	100	0	0	0
	737				100	100	100	0	0	0
	738				50	50	50	100	100	100
	722				100	100	100	100	100	100
	712				0	0	0	50	50	50
Minimum voltage (p.u)		0.9497	0.9578	0.9445	0.9648	0.9736	0.9630	0.9622	0.9712	0.9598
Max. Voltage Regulation(p.u)		0.0503	0.0422	0.0555	0.0352	0.0264	0.0370	0.0378	0.0288	0.0412
Improvement in Maximum Voltage Reg. (%)		----	----	---	30.0198	37.4407	33.3333	24.8509	31.7535	25.7657
Total active power loss(kW)		31.5629	23.6694	30.4423	25.3144	20.4179	25.6992	25.4665	20.4095	24.9962
Improvement in active power loss reduction (%)		---	---	---	19.797	13.7371	15.5806	19.3151	13.7726	17.8899
Total active Power demand(kW)		885.5629	789.6694	1163.4423	879.3144	786.4179	1158.6992	879.4665	786.4095	1157.9962
Total reactive power loss (kVAr)		24.0124	22.3149	29.1954	20.1642	18.5200	24.8680	20.4053	18.8301	24.6516
Improvement in reactive power loss reduction(%)		----	---	---	16.02588	17.0061	14.8222	15.022	15.6165	15.5634
Total reactive Power demand(kVAr)		442.0124	397.3149	580.1954	438.1642	393.5200	575.8680	438.4053	393.8301	575.6516
Total Feeder Demand (kVA)		989.7457	883.9892	1300.0864	982.4366	879.381091	1293.9118	982.6803	879.51239	1293.18597
Released feeder capacity (kVA)		----	----	-----	7.3091	4.60811	6.1746	7.0654	4.47681	6.90043
Net saving(Rs.)	Best	-----			282308.1142			309007.5027		
	worst				31107.2205			222161.7348		
	Average				270417.3564			307764.2194		
Time of Execution(s)		-----			110.7660			56.4060		

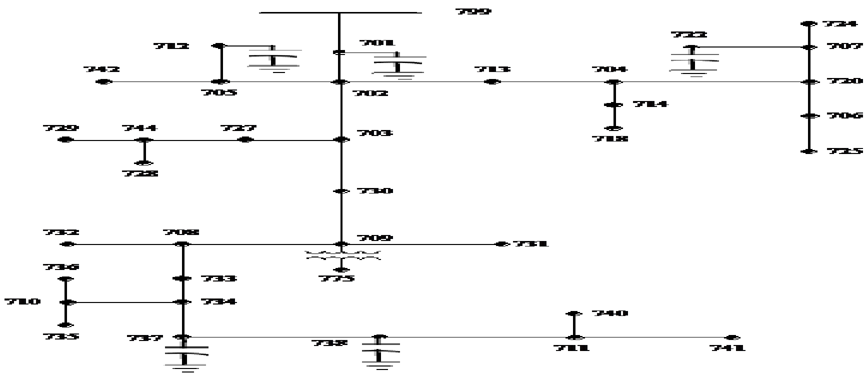

Fig. 5 Single line diagram of 37 bus URDS after capacitor placement

6. Conclusions

In this paper 37-bus unbalanced radial distribution systems is considered for analysis to determine capacitor location and ratings of capacitor banks. This paper presents a simple method to determine suitable candidate buses based on power loss indices for capacitor placement in unbalanced loading is considered for analysis in distribution systems and also addresses capacitor sizing problem for loss minimization using PSO algorithm. An algorithm is developed for optimal capacitor placement and sizing while minimizing power loss and improving the voltage profile. The results indicates efficacy of the proposed method for capacitor placement and sizing. A marginal improvement in voltages has been obtained and time of execution is decreased. It is concluded that PSO is efficient method to solve non linear optimization problems.

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