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DG POWER LOSS REDUCTION USING SOFT COMPUTING TECHNIQUES CONSIDERING OPTIMAL SIZING & LOCATION

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Abstract: In this paper, genetic algorithm (GA) and particle swarm optimization (PSO) techniques are used, to analyze the optimal DG placement for minimization of power losses to facilitate the large-scale integration of DG Into distribution systems. The impact of DG on losses is also analyzed. Soft computing technique PSO is exhibited to be flexibly suitable for execution at any type of power system with the specified system bus data & line data. GA and PSO soft computing optimization techniques have been analyzed and tested on the standard benchmark IEEE 30-bus system. Results obtained after applying both optimization techniques on the American Electric IEEE 30-bus system with the same control variable with maximum & minimum limits and system data have been compared and analyzed. The result validates that the appropriate allocation and size of DG are the significant factors that affect the accommodation of the growing levels of DG in distribution networks.

***Index Terms* - Analytical expression, loss reduction, multiple DG, optimal location, optimal power factor, optimal size.**

I. Introduction

The present power distribution network is continuously being handled with an ever-growing load demand, this increasing load is resulting in increased problem and reduced voltage [1]. The distribution network also has a typical feature that the voltage at nodes reduces, if moved away from a substation. This decrease in voltage is mostly due to an unsatisfactory amount of reactive power. Even in certain industrial zone critical loading may lead to voltage failure. Thus, to improve the voltage profile and to avoid voltage collapse, reactive compensation is required [2-3].

The X/R ratio for distribution levels is low compared to transmission levels, causing high power losses and a drop in voltage magnitude along radial distribution lines [4]. It is well known that loss in distribution systems is meaningfully high likened to that in transmission systems. Such non-negligible losses have a straight effect on the financial issues and total efficiency of distribution utilities [5]. The necessity of improving the total efficiency of power delivery has enforced the power utilities to diminish the losses the distribution level. The distributed generators supply fragment of active power demand, thereby decreasing the current and MVA in lines [6]. Installation of distributed generators on distribution network will help in decreasing energy losses, highest demand losses and upgrade in the network's voltage profile, networks stability and power factor of the networks [7].

Distributed generation (DG) technologies lower than smart grid theory form the mainstay of our world Electric distribution networks [4-5].
The DG technologies are categorised as follows:
(a) Renewable energy sources
(b) Petroleum based sources

The DGs which are based on Renewable energy source are biomass, wind turbines, geothermal, photovoltaic, small hydro and many more. Petroleum based DGs are the IC engines, ignition turbines and fuel cells [8]. Technical, Environmental & economic factors play a massive role in DG expansion. In accord with the Kyoto agreement related to climate transformation, various initiations were taken for reducing carbon releases, and because of which, the dissemination of DGs in distribution systems upsurges [9].
The existence of Distributed generation in distribution networks is a significant challenge in terms of technical and safety issues [10]. Thus, it is critical to assess the technical effects of DG in power networks. Therefore, the generators needed to be linked in distributed systems in in a proper manner without compromising power system reliability and quality.

Evaluation of the procedural effects of DG in the power grids is very critical and backbreaking. Insufficient allocation of DG in terms of its location and capacity may lead to a rising in fault currents, reasons voltage variants, interfere in voltage-control procedures, reduce or increase losses, increase system capital and operational costs, etc. [11]. Furthermore, proper installation of DG units is a matter of sheer concern, and thus the sitting as well as sizing of DG units must be cautiously addressed.

Examining the optimisation problem is the main inspiration for this research work. DG placement is basically a composite combinatorial optimisation issue, that needs contemporaneous optimisation for multiple objectives [14], for minimisations of real and hidden power losses, carbon giving off, node voltage anomaly, line loading as well as short circuit aptitude along with maximisation of network reliability etc.

The objective is to find out the optimal size of DG units in power distribution network. In [12], sensitivity analysis had been used for discovery of the optimal location of DG. In [13], the optimal location of DGs was predicted by discovery V-index. In [14], Loss sensitivity factor had been used for discovery the optimal location of DGs. There are various optimisation techniques used in the literature. In [4], an investigative method for finding out the optimal location of DG is presented. In majority of current works, population-based evolutionary procedures are utilized as solution plans. It also comprises of genetic algorithm (GA) [15], evolutionary programming [16], and particle swarm optimisation [17-18] etc. GA and PSO are population-based meta-heuristics algorithms which possesses the merits such that conventional non-dominated results may achieve in a one tries due to its multi-point search competence. These methods are also less inclined towards problems related to dimensionality, nevertheless, convergence is not definite always.

II. MATHEMATICAL MODELLING

2.1 SOLUTION ALGORITHM

This part of methodology represents a modelled design of projected investigative approach. This projected logical method has goals to regulate the optimum sized DG for specified radial distribution system in order to minimize both voltages drop as well as actual power loss. The anticipated tactic needs to be followed as below mentioned norms:

1. Distribution network chosen here is of radial type and is a balanced network.
2. The value of DG's Power factor should be known. Suppose a distinctive N-bus radial power distribution system as made known in figure 1. Here, I_k represents phase current of branch K whereas, I_{LK} represents phase current of load linked at node K. Whenever any DG is positioned at any bus as represented in figure 2, this inoculates current I_{DG} to circuit and by this means modifies the currents of all branches connecting in between from bus K to sub-station buses. Though, currents in residual branches remains unchanged during DG placement at k bus.

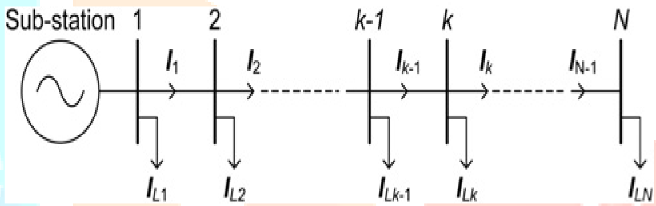

Fig. 1. A N-bus radial power distribution system

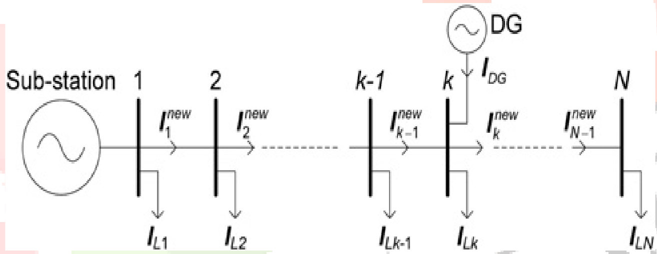

Fig. 2. Typical N-bus radial distribution system with DG placement at k bus

The inoculated current when DG is positioned k bus can be denoted by the given equation

$$I_{DG} = I_{aDG} + jI_{rDG} = I_{aDG}(1 + j\tan\emptyset) \quad (1)$$

Where I_{aDG} and I_{rDG} represents actual and hidden part, respectively, of I_{DG} and $\emptyset$ is representing phase angle of I_{DG}. Now, the altered current in i branch due to DG allocation at bus k is represented as

$$I_i^{new} = I_i - D_i I_{DG} = (I_{ai} - D_i I_{aDG}) + j(I_{ri} - D_i I_{aDG}\tan\emptyset) \quad (2)$$

Where I_i represents phase current in I branch without DG and I_i^{new} is the modified phase current in i branch after DG allocation. D_i can be represented by below mentioned equation:

$$D_i = \begin{cases} 1, \text{for branch i from bus 1 to bus k} \\ 0, \quad \text{otherwise} \end{cases}$$

Encompassing the same perception for m numbers of DGs concurrently in pre assumed N-bus network, now the revised current in I branch may be denoted as follows:

$$I_i^{new} = I_i - \sum_{k=1}^{m} D_{ik} I_{DG}^{k} = \left(I_{ai} - \sum_{k=1}^{m} D_{ik} I_{aDG}^{k}\right) + j\left(I_{ri} - \sum_{k=1}^{m} D_{IK}\, I_{aDG}^{k}\tan\emptyset^{K}\right) \quad (3)$$

Where, I_i^{new} shows modified phase current in i branch; I_k DG is the phase current which is inserted current by kth DG. Here, I_{aDG}^{k} and $\emptyset^{k}$ represents active component along with phase angle of I_k. The value of D $_{ik}$ is shown by the following relation

$$D_{ik} = \begin{cases} 1, \quad \text{for branch i from bus 1 and bus at which kth DG is located} \\ 0, \quad \text{otherwise} \end{cases}$$

2.1.1 *Exact Loss formula*

The total active power loss in power systems is represented by (3.4), popularly known as "exact loss formula" [16]

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}\left[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j - P_iQ_j\right)\right] \quad (4)$$

Where,

$$\alpha_{ij} = \frac{r_{ij}}{V_i V_j}\cos(\delta_i - \delta_j), \beta_{ij} = \frac{r_{ij}}{V_i V_j}\sin(\delta_i - \delta_j); V_i \angle \delta_i$$

Complex voltage at the bus i is shown by $r_{ij} + jx_{ij} = Z_{ij}$

The ij[th] element of $[Z_{bus}]$impedance matrix; $P_i$and P_j shows real power inoculations at the ith and jth buses, respectively; Q_i and Q_j the hidden power inoculations at the i[th] and j[th] buses resp. and N represents total number of buses.

2.1.2 Real power loss

The total true power loss [17], denoted as P_L in the distinctive assumed N-bus system as shown in figure 1, is represented by given equation $P_L = \sum_{i=1}^{N-1} I_i^2 R_i = \sum_{i=1}^{N-1}(I_{ai}^2 + I_{ri}^2)R_i$ (5)

Where I_i is representing current through i branch by I_{ai} and I_{ri} being it's true & hidden components, respectively, and R_i represents resistance of i branch. The total active power loss with location of m DGs is given by

$$P_L^{new} = \sum_{i=1}^{N=1}(I_i^{new})^2 R_i = \sum_{i=1}^{N=1}\left[\left(I_{ai} - \sum_{k=1}^{m} D_{ik} I_{aDG}^k\right)^2 + \left(I_{ri} - \sum_{k=1}^{m} D_{ik} I_{aDG}^k \tan\emptyset^K\right)^2\right] R_i \quad (6)$$

Using (4) and (5), standardized loss saving P_S related to multiple DG allocation represented as in (6).

2.1.3 Reactive power loss

Total hidden power loss, shown as $Q_L$in a in the distinctive assumed N-bus system can be represented as below

$$Q_L = \sum_{i=1}^{N-1} I_i^2 X_i = \sum_{i=1}^{N-1}(I_{ai}^2 + I_{ri}^2)X_i \quad (7)$$

The total hidden or reactive loss of power after allocation of m DGs is given by

$$Q_L^{new} = \sum_{i=1}^{N=1}(I_i^{new})^2 X_i = \sum_{i=1}^{N=1}\left[\left(I_{ai} - \sum_{k=1}^{m} D_{ik} I_{aDG}^k\right)^2 + \left(I_{ri} - \sum_{k=1}^{m} D_{ik} I_{aDG}^k \tan\emptyset^k\right)^2\right] X_i \quad (8)$$

Using (7) and (8) the normalized hidden power loss saving Q_L can be calculated with multiple DG locations.

2.1.4 Objective function and constraints

Objective function of this problem goals to minimize the true power loss and getting improved voltage framework for all system buses. The problem can be modelled mathematically as

$$\text{Total loss} = \left(\sum_{k=1}^{N_b} |I_k^2| \times R_k\right) \quad (9)$$

Subject to Active and Hidden power injections

$$B''\delta - G'V + P_G = P_D$$
$$G''\delta - B'V + Q_G = Q_D \quad (10)$$

Voltage limits constraints

$$|V_k^{min}| \le |V_k| \le |V_k^{max}| \quad (11)$$

Feeder capacity constraints

$$|I_F| \le |I_F^{max}|$$
$$|I_R| \le |I_R^{max}| \quad (12)$$

DG true and hidden power constraints

$$P_{DG}^{min} \le P_{DG} \le P_{DG}^{max}$$
$$Q_{DG}^{min} \le Q_{DG} \le Q_{DG}^{max} \quad (13)$$

Where, N_b represents number of buses, I_k gives current moving out of branch k, R_k shows branch resistance of k branch. Other than this, B'', B', G'' and G' represents the parameters developed with dimensions $(N_b \times N_b)$, δ shows voltage angles of buses $(N_b \times 1)$, V_{max} and V_{min} shows highest and smallest permissible voltages $(N_b \times 1)$, parameters P_G and Q_G denotes the true and hidden power generation for substation $(N_b \times 1)$ and parameters P_D and Q_D denotes the actual and hidden power loads $(N_b \times 1)$, P_{min}DG and Q_{min}DG shows actual and hidden power capacity of the DGs $(N_b \times 1)$, Imax F & Imax R shows forward & reverse flow capabilities of distribution lines $(N_f \times 1)$, with N_f representing the number of distribution feeders.

The abovementioned formulas show the sum of the power at any random bus, which represents the power balance equation for true and hidden power. The formulae of this constraint are represented as follows

2.2

The established mathematical representation as mentioned in preceding part may be utilized to resolve the optimum sizes and sites for DGs concerning the pre assumed network with pre mentioned constraints. For allocation of m number of DGs in an N-bus system, here, C_m^N possible combinations are there for various buses. When $m \ll N$, group numbers turn out to be large and that's why it is calculative monotonous for analysis of all combinations. Furthermore, the calculative process of projected algorithm may be classified into the following two major steps:

First of all, an arrangement of m number of buses appropriate for DG assembly is recognized. For that, firstly the optimum size of k[th] DG is computed at the bus by the help of below mentioned equation, attained from (18) by substituting m = 1

$$I_{aDG}^k = \frac{\sum_{i=1}^{N-1} D_i(I_{ai} + I_{ri}\tan\emptyset^k)\left(w_1\left(\frac{R_i}{P_L}\right) + w_2\left(\frac{X_i}{Q_L}\right)\right)}{\sum_{i=1}^{N=1}(D_i \sec\emptyset^k)^2\left(w_1\left(\frac{R_i}{P_L}\right) + w_2\left(\frac{X_i}{Q_L}\right)\right)} \quad (14)$$

In unison, the advantage of k[th] DG is too calculated by using (8) and the same practice is followed for computing the same for all other buses. The highest benefit providing bus is nominated as the candidate bus connection of k[th] DG is done with candidate bus. The same practice is followed then for identifying other preceding candidate buses.

Secondly, by using above equation best size of every DG in consideration with all the buses are recognized similarly and after that the same has been calculated by the help of above equation.

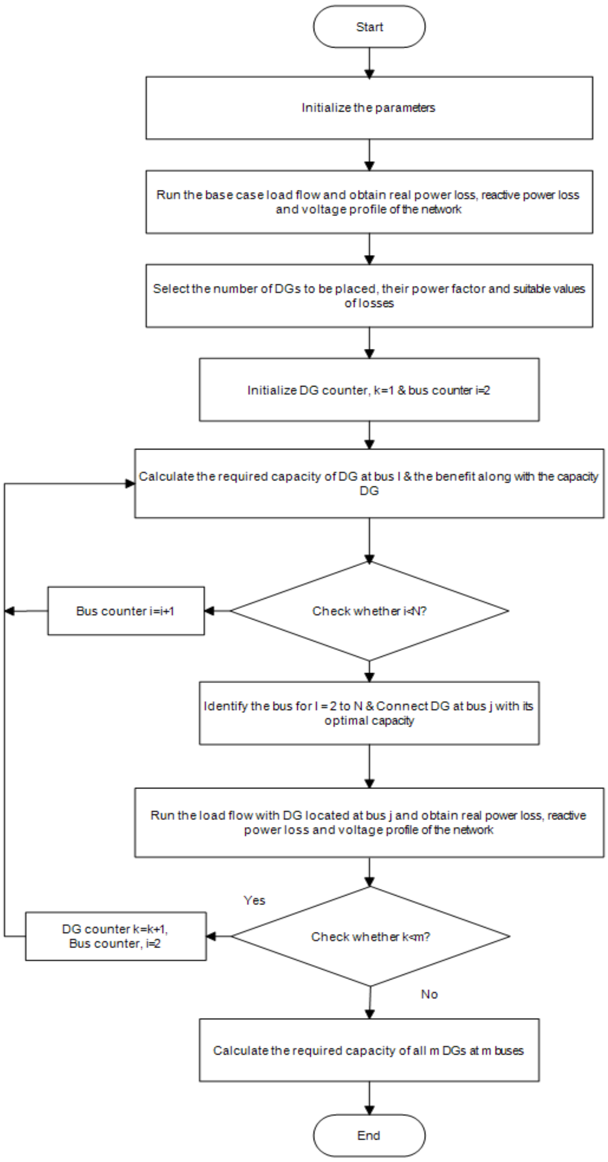

Fig. 3. Flowchart representing projected algorithm

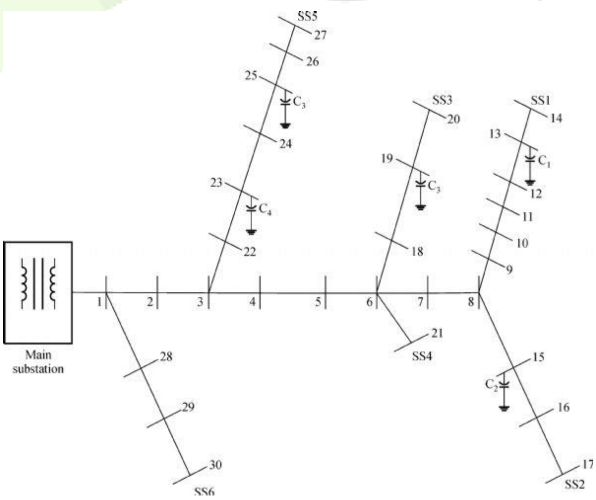

Fig. 4. A typical one-line diagram for 12.66 kV, 30-bus radial type distribution System

III. RESULTS & DISCUSSION

The above-mentioned algorithm is designed in MATLAB environment and same is executed for considered parameters and implemented at two different test systems for determining the optimal size and allocation of DGs. Regarding both the test system, various values of w_1 and w_2 are considered as (a)$w_1 = 1$; and$w_2 = 0$; (b) $w_1 = 0.5$; and $w_2 = 0.5$; and (c) $w_1 = 0$ and $w_2 = 1$.

Other than that, two dissimilar power factors of DG are taken under consideration as follows:

Firstly, all DGs operating at Unity power factor and secondly all DGs functioning at a power factor which is identical to the power factor of total system load [19]. The below mentioned test systems are measured for the optimum allocation and size of DGs by the established algorithm.

The projected method is verified on three different test arrangements of different sizes, demonstrating that it may be applied in DGs of several configurations and sizes. The second test system is 30-bus system [20], the total true power and hidden power loads for this system are 3.72 MW and 2.3 Mvar. The primary true and hidden power losses in the system are 0.211 MW and 0.143 Mvar. Third system is a Genetic algorithm 30-bus system [21], the total true power and hidden power loads considering this system are 3.80 MW and 2.69 Mvar. Initial real and reactive power losses are 0.225 MW and 0.102 Mvar in the system. On the basis of previously designated methodologies, the optimum size of DGs is computed for all buses for the two test systems. Fig.5 and Fig.6 show the best sizes of DG unit at all buses for by using PSO and Genetic algorithm for 30 bus distribution test systems, respectively. With the help of FIS editor optimal location of DG unit is found where real power loss is more and voltage is low. The optimal locations of DG unit are at bus 5,6 and bus 7.

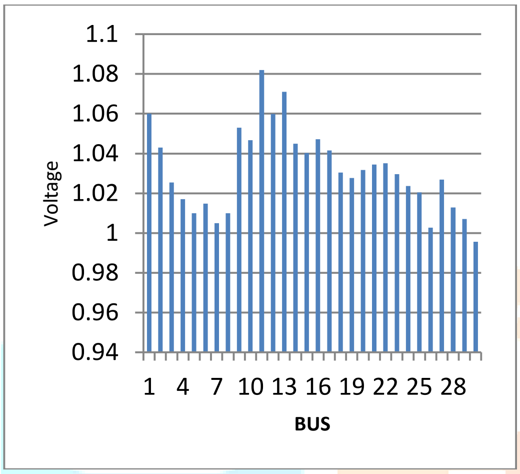

Fig. 5. Voltage profile for PSO 30-bus radial distribution System

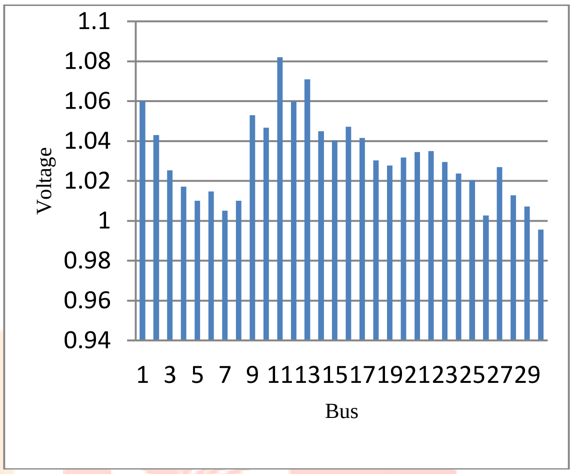

Fig. 6 Voltage profile for Genetic algorithm 30-bus radial distribution System

The Total losses for the corresponding optimal DG unit sizes are shown in Fig.7 and Fig.8 shows Elapsed time.

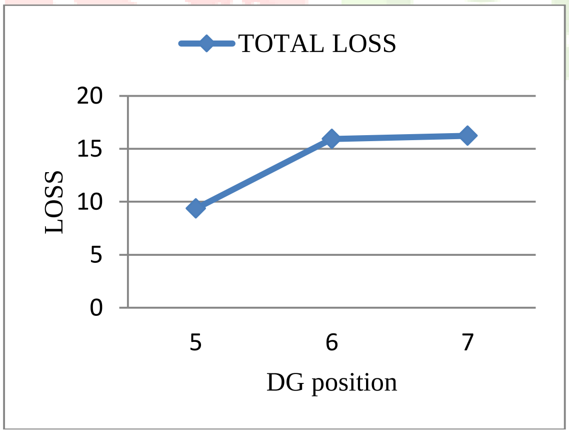

Fig. 7. Total Loss of DG of 30 bus system at 5, 6, 7 position

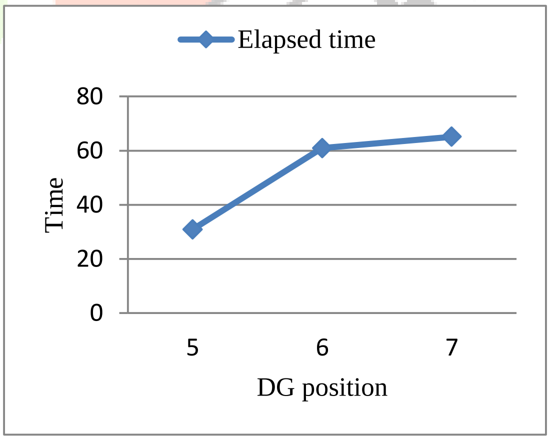

Fig. 8. Elapsed time 30 bus system at 5, 6, 7 position

Results obtained are tabulated in Table 1. Considering the different test systems, the results of projected technique related to the total power loss, maximum and minimum voltage and elapsed time are mentioned in table. It is observed that the total power losses are meaningfully abridged for all test systems.

Table 1. Results of proposed method for test systems and Genetic algorithm

System Type	30 BUS			Genetic algorithm 30 BUS system
	With 5 DG	With 6 DG	With 7 DG	
Maximum Voltage	1.082	1.082	1.082	1.082
Minimum voltage	0.995	1.005	1.003	0.995
Total loss	9.375	15.938	16.240	9.385
Elapsed time in Second	30.860	60.932	65.139	109.946

IV. CONCLUSION

The size of DG unit is one of the decisive factors in the scheduling and operation of active distribution networks. This work presents a comparative analysis of PSO and GA optimization Techniques to determine the optimal size of DG. These methods are easily implementable and are quicker as per the given correctness. It validates that the GA optimization methods may save enormous power and attain noteworthy enhancement in voltage stability. Fitting of DG unit at one position at a time is evidenced to be one of the effective assumptions in this work. However, this work does not consider the other benefits of DG as well as economics of it. The PSO method and GA method needs a smaller number of iterations to reach convergence more accurately and not sensitive to the factors. This work finds the optimal power flow on the standard radial IEEE 30 bus system. This work concerns a general cost minimization problem to solve the power flow problem based on IEEE 30 bus system. In future works, this system can implement for other type of bus systems. It can be extracted from local minima by changing the tolerance values.

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