Optimal Placement of Distributed Generation Using Bacterial foraging Optimization in an Electrical Distribution System

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Abstract- Distributed generation (DG) has been placed in electrical distribution networks widely due to line loss reduction, environmental benefits, better voltage profile, postponement of system upgrading, and increasing reliability. Optimization techniques are tools which can be used for placement and sizing of the DG units in the distribution system. The impacts of DG placement issues, such as power loss minimization and voltage profile, should be analyzed effectively by proposing a method of locating and sizing DG units. This paper proposes Bacterial Foraging Optimization (BFO) algorithm technique for optimal placement of DG units in Distribution System (DS) to minimize the total real power loss, improve power factor and to regulate the voltage profile. BFO is a recently developed nature-inspired optimization technique, which is based on the foraging behavior of E. coli bacteria. To determine the validity of the BFO algorithm, a standard IEEE 69 bus radial distribution feeder system is examined with two test cases. The results show that the proposed BFO algorithm is more efficient, and capable of handling mixed integer nonlinear optimization problems effectively.

Keywords- Distributed Generation, Optimal DG size, Bacterial Foraging Optimization (BFO), E. coli,DS.

NOMENCLATURE

$S_{Load,k}$ Apparent load power at bus $k$
$S_{system,j,k}$ System apparent power flows from bus $j$ to bus $k$
$S_{rated,j,k}$ Apparent rated power flows from bus $j$ to bus $k$
$S_{rated,k,j}$ Apparent rated power flows from bus $k$ to bus $j$
$S_{system,k}$ Apparent load power at bus $k$
$P_j$ Active power flows from bus $j$ to bus $k$
$Q_j$ Reactive power flows from bus $j$ to bus $k$
$N$ Number of buses
$V_j$ Bus voltage at bus $j$
$V_k$ Bus voltage at bus $k$
$A P_k$ Active power injected bus $k$
$R P_k$ reactive power injected bus $k$
$L_j$ Load demand at bus $j$
$S_{sys,j,k}$ System apparent power flows from bus $j$ to bus $k$
$V_{max}$ Maximum specified allowable voltage
$P_{DG,j}$ Dispatchable DG rated active power at bus $j$
$Q_{DG,j}$ Dispatchable DG rated reactive power at bus $j$
$r_{k}$ Line resistance connecting buses $j$ and $k$
$x_{k}$ Line reactance connecting buses $j$ and $k$
$\mu_p$ Real power multiplier when there is no real power source set active power multiplier to 0 or when there is real power source set to 1
$\mu_q$ Reactive power multiplier when there is no real power source set active power multiplier to 0 or when there is real power source set to 1
$S_{max}$ Maximum DG unit size in KVA
$S_{min}$ Minimum DG–unit size in KVA
$p_{DG,j}^{max}$ Maximum DG unit’s working power factor
$p_{DG,j}^{min}$ Minimum DG unit’s working power factor

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I. INTRODUCTION

With the increasing level of global warming due to emissions of CO₂, renewable based distributed generation (DG) should play a major role in electrical power generation. DG may be defined as a small scale generating resource, placed near to load being served or at low voltage distribution side [1]. DG refers to small sources ranging between 1 kW and 50 MW, which are normally placed close to consumption centers. In general DS is designed for one-way power flow. The insertion of DG in the DS violates this basic assumption and can disrupt distribution operation if not carefully employed, potentially causing islanding, protection disturbances, upset voltage regulation, and other power quality problems. DG normally follows the utility voltage and injects a constant amount of real and reactive power [3].

The optimal placement and sizing of DG units on the DS has been analyzed to achieve various solutions. The objective was the minimization of the active losses of the feeder or the minimization of the total network supply costs, which includes generators operation and losses compensation or even the best utilization of the available generation capacity. A stochastic multi-objective model for placement of DG in electrical distribution networks is proposed in [3] with a binary particle swarm optimization (PSO) algorithm. The DS expansion planning strategy with DG systems with intermittent power generation is presented in [4] to obtain optimal solutions for system planners. A DG placement planning study framework is brought in [5] that includes a coordinated reconfiguration feeder and voltage control to calculate the maximum allowable DG capacity at a given node in the electrical distribution system. Works have been dealing with the DG optimal placing and sizing problem by means of multi-objective optimization (MOO) tools, with a considerable number of them based on heuristic approach. Some basic concepts about MOO are introduced in order to support the methods comprehension. The MOO consists in minimize or maximize simultaneously a set of objectives subject to a number of constraints. The process of optimization in a multi-objective scenario occurs in two stages: the determination of the solution set, where all objective function values of each solution cannot be enhanced at the same time and the human decision making whose criteria can be applied before, after or even during the optimization process.

![Fig: 1: Sample two-bus system with one DG](https://via.placeholder.com/150)

In [6] a distributed micro grid model has been introduced to optimize best location and the capacities within DG micro grid, in which wind power and photovoltaic power are taken into consideration with both PSO and Elitism Genetic Algorithm (EGA). A multi-objective index-based approach for optimal location of DG and determining the size of DG units in electrical distribution systems with different load models based on PSO is introduced in[7,8] and a combined genetic algorithm is presented in[9] for optimal location and sizing of DG on DS. A methodology for evaluating the impact of DG-units on power loss, reliability, and voltage profile of distribution networks was presented in reference [11].

A heuristic approach for optimal location and size of DGs in distribution networks, with the objectives of minimizing the power loss and voltage profile improvement is proposed in [6]. In [10] a Newton-Raphson algorithm based load flow program is used to solve the load flow problem. Moreover, some heuristic search requires exhaustive search for all possible locations which may not be applicable to more than one DG.

As a contribution to the methodology for DG placement analysis, in this paper it is proposed a BFO algorithm for the allocation of distributed generators in distribution networks, in order to improve voltage profile and line loss reduction in DS. The organization of this paper is as follows. Section II addresses the problem formulation. Section III addresses the impact of the DG placement and size on DS. The BFO algorithm is represented in Section IV. Pseudo code for a BFO computation procedure for the problem is given in Section V. Simulation result on the test systems are illustrated in Section VI. Then, the conclusion is given in Section VII.

II. PROBLEM FORMULATION

Importance of placing a DG in distribution networks is to reduce the total system real power loss while satisfying certain operating constraints. In other words, the problem of DG application can be interpreted as determining the optimal placement and size of the DG to satisfy the desired objective function subject to equality and inequality constraints. Reliability, accuracy, and flexibility of the DG solution algorithm are influenced by the load flow analysis used. So the overall algorithm accuracy is highly depends on that analysis. It can be otherwise called that the load flow analysis is the heart of the DG-unit solution algorithm. Based on that the load flow algorithm used in [10] is applied in this paper. In Fig.1, a sample two bus system including DG-unit is considered. The mathematical formulations of the mixed integer nonlinear optimization problem for the DG-unit application are as follows: [9]

The objective function is to reduce the real power loss

\[
Obj.\,Fun = \min \left( \sum_{j=0}^{n} \frac{P_j^2+Q_j^2}{V_j^2} \right) \ast r_k \quad (1)
\]

The equality constraints are the three nonlinear recursive power-flow equations describing the system [10]

\[
P_j - r_k \frac{(P_j + jQ_j)}{V_j^2} - P_{L,k} + \mu \nu \alpha \, P_k - P_k = 0 \quad (2)
\]

\[
Q_j - x_k \frac{(P_j + jQ_j)}{V_j^2} - Q_{L,k} + \mu \nu \beta \, Q_k - Q_k = 0 \quad (3)
\]

Vol. 6 Issue 06, June - 2017

ISSN: 2278-0181

IJERTV6IS060167

www.ijert.org

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IJERTV6IS060167

www.ijert.org

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The economic advantages are the reduction of transmission and distribution costs, reduction of electricity price, and saving of fuel. Environmental advantages entail reductions of sound pollution and emissions of greenhouse gases. The technical benefits of DGs in existing networks are minimizing power losses, reducing the emission of pollutants, improving power quality, and relieving transmission and distribution congestion [4]. It can also provide stand-alone remote applications with the required power. Therefore, the optimal placement and sizing of DGs attract active research interest.

Several researchers have worked in this area [7-13]. DGs are placed at optimal locations to reduce losses [7]. Some researchers have presented load flow algorithms to find the optimal size of DGs at each load bus [8, 9]. Wang and Nehrir have shown analytical approaches for optimal placement of DGs in terms of loss [10]. Chiradeja quantified the benefit of reduced line loss in a radial distribution feeder with a concentrated load [11]. Further, many researchers have used evolutionary computational methods for finding the optimal DG placement [14-19]. Mithulananthan used a genetic algorithm (GA) for placement of DGs to reduce the losses [15]. Celli and Ghiani used a multi-objective Evolutionary algorithm for the sizing and placement of DGs [18]. Nara et al. used a tabu search algorithm to find the optimal placement of DGs [19]. Since the analytical methods are generally poor to solve this type of function, almost many of the related papers are based on heuristic methods. Due to the discrete nature of the sizing and placement problem, the objective function has a number of local minima. The hybrid particle swarm optimization (HPSO) algorithm has applied as a useful tool for engineering optimization, to solve complex optimization problems [10-15]. This paper presents a novel search approach with respect to the voltage profile for the optimal placement of DGs using the BFO algorithm and compares it with the Bee colony optimization (BCO) algorithm and other methods. Optimal bus locations are determined to obtain the best objective. The multi-objective optimization simultaneously covers the optimization of both the voltage margin and active power loss. The problem is defined and the objective function is introduced to maximize the voltage profile index, and minimize losses. Hence, an algorithm is developed to assess the voltage profile based on the loadability limit. This method is executed on the IEEE 69 bus test systems, showing the robustness of this method in finding the optimal sizing and placement of DGs, efficiency for improvement of voltage profile, power factor improvement and reduction of system real power losses [14].

IV. BACTERIAL FORAGING OPTIMIZATION IMPLEMENTATION

The BFO algorithm was first represented by Pasino in 2002. The idea in this method was adopted from biological and physical living behavior of E. coli bacteria existing in human intestine. This algorithm has three main processes namely Chemotaxis, Reproduction, and Elimination fault Dispersal. The bacteria is exponential with a relatively short time to double. The E. coli bacterium has a guidance system that enables it to search for food and try to avoid noxious substances. The E. coli grows in the intestine. This algorithm has three main processes namely Chemotaxis, Reproduction, and Elimination fault Dispersal. When E. coli grows, it gets longer, and then divides in the middle into two “daughters.” Given sufficient food and held at the temperature of the human gut of 37 ° C, E. coli can synthesize and replicate everything it needs to make a copy of itself in about 20 min; hence growth of a population of bacteria is exponential with a relatively short time to double. The E. coli bacterium has a guidance system that enables it to search for food and try to avoid noxious substances. The behavior of the E. coli bacterium, will be explained as its actuator (the flagellum), “decision making,” sensors, and closed-loop behavior. This section is based on the work in [24, 25]. Fig 2 shows the simplified BFO optimization flowchart.
(i) Chemotaxis: An *E. coli* bacterium can decide to move in two different ways depending on its environment. A bacterium is subject to change during its lifetime between the two ways of swimming (swim for a short time) and tumbling. In BFO, one moving unit length with random directions represents tumbling and one moving unit length with the same direction relative to the final stage represents swimming. The mathematical equation for Chemotaxis is expressed as follows:

\[ \theta_i^{(j+1, k, l)} = \theta_i^{(j, k, l)} + C(i) \frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}} \]  

Where

- \( \theta_i \) : location of \( i \)th bacterium
- \( C(i) \) : movement length
- \( \Delta(i) \) : direction random vector
- \( j \) : is representing \( j \)th chemotaxis
- \( k \) : is representing \( k \)th reproduction
- \( l \) : is representing \( l \)th elimination and dispersal

Also, the number of chemotaxis is represented by \( N_C \).

(ii) Reproduction: After the number of \( N_C \) Chemotaxis steps, reproduction step takes place. \( N_{re} \) represents the number of reproduction steps.

(iii) Elimination-Dispersal: The swimming process prepares the conditions for local search and reproduction process speeds up the convergence. In a large space swimming and reproduction for searching global optimal point cannot be sufficient. In bacterial foraging, dispersion takes place after a definite number of reproduction processes. A bacterium is selected with regard to a prearranged probability of \( P_{ed} \) to be dispersed in the environment and moved to another position. These events can effectively prevent trapping in local optimal point. \( N_{ed} \) is the number of elimination and dispersal phenomenon and \( P_{ed} \) is defined for every bacterium with the probability of elimination and dispersal.

A flowchart for BFO algorithm by MATLAB Programming is shown in Figure 2.

V. PSEUDO CODE FOR BFO ALGORITHM:

Step (1): Initialize the parameters,

- **S**: Total number of bacteria
- **P**: Number of parameters to be optimized
- **N_C**: Number of chemotactic steps
- **N_S**: Number of swarming
- **N_re**: Number of reproduction steps
- **N_ed**: elimination-dispersal steps
- **d_attract**, **w_attract**, **d_repellant**, **w_repellant**: Attractant and repellant values
- **P_{ed}**: Probability of elimination-dispersal
- **C(i)**: step size

Step(2): Elimination-Dispersal loop \( l = l + 1 \)

Step(3): Reproduction loop \( k = k + 1 \)

Step(4): Chemotactics loop \( j = j + 1 \)

Step(5): Every bacterium \( i = i + 1 \)

[a] Compute fitness function \( J(i,j,k,l) \)

Let, \( J(i,j,k,l) = J(i,j,k,l) \) to save this value. We may find a better cost via a run.

[b] Let, \( J(\text{last}) = J(i,j,k,l) \) to save this value. We may find a better cost via a run.

[c] Tumble: Generate a random vector \( \Delta(i) \) such that \( 1 <= \Delta(i) <= -1 \).

[d] Move: Let, \( \theta^*(j+1,k,l) = \theta^*(j,k,l) + C(i) \cdot (\Delta(i) / \sqrt{(\Delta^T(i) \cdot \Delta(i))}) \)

[e] Compute \( J(i,j+1,k,l) \) and let, \( J(i,j,k,l) = J(i,j,k,l) + J_{cc} \)
Swim: Let, \( m = 0 \) (counter for swim length)

(i) While \( m < N_s \)

(ii) Let, \( m = m + 1 \)

(iii) if \( J(i,j+1,k,l) < J(i,j,k,l) = J(i,j,k,l) + J_{cc} \)

Let, \( J_{\text{last}} = J(i,j+1,k,l) \)

\[ \theta^i (j+1,k,l) = \theta^i (j,k,l) + C(i) \Delta^i (\Delta^i(i) \Delta(i)) \]

(iv) else, let \( m = N_s \)

[g] Go to next bacterium, if \( i \neq S \)

Step(6): if \( j < N_c \), go to step(4)

Step(7): Reproduction:

[a] for the given \( k \) and \( l \), and for each \( i = 1 \) to \( S \),

(i) Let, \( J_{\text{health}} = \sum_{i=1}^{N_c} J(i,j,k,l) \)

(ii) Sort the fitness in ascending order

[b] The Sr bacteria with worse health value will die, the remaining Sr bacteria with best values will split into two.

Step(8): if \( k < N_r \), go to step(3)

Step(9): Elimination-Dispersal

[a] for \( i = 1 \) to \( S \), with probability \( P_{ed} \), eliminate and disperse each bacterium.

[b] if a bacterium eliminated, then add new one to a random location on the search space.

Step (10): if \( l < N_{ed} \), go to step (2), Else Terminate.

VI. RESULTS AND DISCUSSION

The proposed BFO algorithm is implemented in MATLAB programming, and was executed on an Intel dual core™ PC with 3.0-GHz speed and 4 GB RAM. To check the performance of the proposed BFO algorithm, the 69-bus radial distribution feeder system was considered in different test cases. We studied two test cases with the loads are identical to the values given in [11], i.e. The total demands of the 69-bus system are 3802.19 kW and 2694.60 kVAR. The substation voltage and load power factors in both scenarios were considered as 1.0 p.u. and lagging p.f., respectively.

Fig. 3. Single-line diagram of the 69-bus feeder system

Line loss reduction analysis is based on the simple case of an IEEE 69 bus radial distribution feeder [4] is considered with following cases:

(I) System without DG

(II) System with the inclusion of one DG to share full load

(iii) System with the inclusion of one DG & one Capacitor to share full load

Case (I): System without DG

This is a reference scenario, in which no DG unit is connected to the system (default case). The voltage profiles of the feeder system with out DG placement has shown in Fig. 4.

Fig. 4: Voltage magnitude in p.u volts versus bus numbers before DG placement.

It is observed that from bus number 59 to 64 the voltages in p.u are 0.919, 0.912, 0.9, 0.9, 0.899 and 0.897 respectively. These voltages are the lowest among 69 buses.
Table 1: Optimized results before DG placement

<table>
<thead>
<tr>
<th>Particulars</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real power (MW)</td>
<td>3.892</td>
</tr>
<tr>
<td>Reactive power (MVAR)</td>
<td>2.802</td>
</tr>
<tr>
<td>Active load (MW)</td>
<td>3.802</td>
</tr>
<tr>
<td>Reactive load (MVAR)</td>
<td>2.694</td>
</tr>
<tr>
<td>Total real power Loss (MW)</td>
<td>0.226</td>
</tr>
<tr>
<td>Total reactive power loss (MVAR)</td>
<td>0.202</td>
</tr>
</tbody>
</table>

Case 2: System with one DG to share full load

In this, the voltages are improved in all the buses in particular from 59 to 64 shown in Appendix 1.

![Fitness value versus chemotatic steps for one DG unit connected with actual load](image1)

![Voltage magnitude in p.u volts versus bus No. after one DG placed to share full load](image2)

Table 2: parameters after 1 DG placed to share full load

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Without DG</th>
<th>With DG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Placement of DG (Bus No)</td>
<td>-</td>
<td>61</td>
</tr>
<tr>
<td>value of DG (kVA)</td>
<td>-</td>
<td>1734.8</td>
</tr>
<tr>
<td>Voltage in p.u (volts)</td>
<td>-</td>
<td>0.9961</td>
</tr>
<tr>
<td>Angle (degrees)</td>
<td>-</td>
<td>-0.1507</td>
</tr>
<tr>
<td>Power factor</td>
<td>-</td>
<td>0.9886</td>
</tr>
<tr>
<td>Total power Loss (kW)</td>
<td>226</td>
<td>84.12</td>
</tr>
<tr>
<td>% Loss Reduction</td>
<td>-</td>
<td>62.78</td>
</tr>
</tbody>
</table>

Case 3: System with 1DG and one capacitor to share full load

![Fitness value versus chemotatic steps for one DG plus one capacitor unit connected with active power supply](image3)

![Voltage magnitude in p.u versus bus number for one DG plus one capacitor unit connected to share full load](image4)
Table 4: parameters after one DG unit plus one capacitor is connected with active power supply.

<table>
<thead>
<tr>
<th>Particulars</th>
<th>With DG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Placement of DG (Bus No)</td>
<td>61</td>
</tr>
<tr>
<td>value of DG (kVA)</td>
<td>1654.8</td>
</tr>
<tr>
<td>Placement of Capacitor (Bus No)</td>
<td>50</td>
</tr>
<tr>
<td>value of Capacitor (kVAR)</td>
<td>1771</td>
</tr>
<tr>
<td>Voltage at DG placed bus in p.u (volts)</td>
<td>0.9977</td>
</tr>
<tr>
<td>Angle at DG placed bus in (degrees)</td>
<td>0.5908</td>
</tr>
<tr>
<td>Power factor at DG placed bus</td>
<td>0.9245</td>
</tr>
<tr>
<td>Voltage at capacitor placed bus in p.u</td>
<td>0.9838</td>
</tr>
<tr>
<td>Angle at capacitor placed bus in (degrees)</td>
<td>-0.487</td>
</tr>
<tr>
<td>PF at capacitor placed bus (lead)</td>
<td>0.9947</td>
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<tr>
<td>Total power Loss (kW)</td>
<td>85.4</td>
</tr>
<tr>
<td>%Loss Reduction</td>
<td>62.21</td>
</tr>
</tbody>
</table>

VII. CONCLUSIONS
In this paper, a new population-based BFO has been implemented to solve the mixed integer nonlinear optimization problem. The objective function was to reduce the total system real power loss subject to equality and inequality constraints. Simulations were conducted on the IEEE 69-bus radial distribution feeder systems. The proposed BFO algorithm successfully implemented the optimal solutions at various test cases. The BCO algorithm is simple, easy to implement, and capable of handling complex optimization problems.

Appendix 2: Optimized values after one DG unit is connected to share normal load in 69 bus system using BFO technique

<table>
<thead>
<tr>
<th>Bus No</th>
<th>Voltage (p.u)</th>
<th>Angle(degrees)</th>
<th>Power factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.99963062</td>
<td>-0.001</td>
<td>0.9999995</td>
</tr>
<tr>
<td>2</td>
<td>0.999926124</td>
<td>-0.002655453</td>
<td>0.99996474</td>
</tr>
<tr>
<td>3</td>
<td>0.999855678</td>
<td>-0.004949389</td>
<td>0.99987751</td>
</tr>
<tr>
<td>4</td>
<td>0.999432299</td>
<td>-0.01166437</td>
<td>0.9993879</td>
</tr>
<tr>
<td>5</td>
<td>0.9994842983</td>
<td>0.0278304</td>
<td>0.999612129</td>
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<td>6</td>
<td>0.990079005</td>
<td>0.068559551</td>
<td>0.997650714</td>
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<td>7</td>
<td>0.988978119</td>
<td>0.077936818</td>
<td>0.996944463</td>
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<td>8</td>
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<td>0.082270981</td>
<td>0.99667651</td>
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<td>9</td>
<td>0.981698373</td>
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<td>10</td>
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<td>0.229815898</td>
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<td>11</td>
<td>0.976211313</td>
<td>0.302187767</td>
<td>0.954687674</td>
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<td>12</td>
<td>0.973038305</td>
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<td>13</td>
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<td>14</td>
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<td>15</td>
<td>0.971323098</td>
<td>0.109703624</td>
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<td>16</td>
<td>0.970012209</td>
<td>0.245940674</td>
<td>0.990154885</td>
</tr>
</tbody>
</table>

Appendix 2: Optimized values after one DG and one capacitor connected to share full load in 69 bus system using BFO technique

<table>
<thead>
<tr>
<th>Bus No</th>
<th>Voltage (p.u)</th>
<th>Angle(degrees)</th>
<th>Power factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.99964995</td>
<td>-0.001740283</td>
<td>0.9999984</td>
</tr>
<tr>
<td>2</td>
<td>0.99992990</td>
<td>-0.002480619</td>
<td>0.9999692</td>
</tr>
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<td>3</td>
<td>0.999865349</td>
<td>-0.004512457</td>
<td>0.9999881</td>
</tr>
<tr>
<td>4</td>
<td>0.99518486</td>
<td>-0.014211835</td>
<td>0.9988901</td>
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<tr>
<td>5</td>
<td>0.995425256</td>
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<td>6</td>
<td>0.99177744</td>
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<td>7</td>
<td>0.99020142</td>
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<td>0.9984317</td>
</tr>
<tr>
<td>8</td>
<td>0.989760495</td>
<td>-0.051064597</td>
<td>0.9996968</td>
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<tr>
<td>9</td>
<td>0.98371427</td>
<td>-0.052704446</td>
<td>0.9986114</td>
</tr>
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</table>
VIII. REFERENCES


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