A combined sensitivity factor based GA-IPSO approach for system loss reduction and voltage profile enhancement

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ABSTRACT

Though several algorithms for optimizing DG location and size in a network with the aim of reducing system power losses and enhancing better voltage profile have already been proposed, they still suffer from several drawbacks. As a result much can be done in coming up with new algorithms or improving the already existing ones so as to address this important issue more efficiently and effectively. Majority of the proposed algorithms have emphasized on real power losses only in their formulations. They have ignored the reactive power losses which is key in the operation of power systems. In modern practical power systems reactive power injection plays a critical role in voltage stability control, thus the reactive power losses need to be incorporated in optimizing DG allocation for voltage profile improvement. The results of the few works which have considered reactive power losses in their optimization can be improved by using more recent and accurate algorithms. This research work aimed at solving this problem by proposing a hybrid of GA and IPSO to optimize DG location and size while considering both real and reactive power losses. Both real and reactive power flow and power loss sensitivity factors were utilized in identifying the candidate buses for DG allocation. This reduced the search space for the algorithm and increasing its rate of convergence. This research considers a multi-type DG; type 1 DG (DG generating real power only), type 2 DG (DG generating both real and active power) and type 3 DG (DG generating real power and absorbing reactive power).

Key words: Distributed Generation (DG), Particle Swarm Optimization (PSO), Genetic Algorithm (GA), system loss reduction, voltage profile improvement.

INTRODUCTION

Distribution Systems

The objective of power system operation is to meet the demand at all the locations within power network as economically and reliably as possible. The traditional electric power generation systems utilize the conventional energy resources, such as fossil fuels, hydro, nuclear etc. for electricity generation. The operation of such traditional generation systems is based on centralized control utility generators, delivering power through an extensive transmission and distribution system, to meet the given demands of widely dispersed users. Nowadays, the justification for the large central-station plants is weakening due to depleting conventional resources, increased transmission and distribution costs, deregulation trends, heightened environmental concerns, and technological advancements [1].

Distribution Systems Power Loss Minimization

Normally, the real power loss reduction draws more attention for the utilities, as it reduces the efficiency of transmitting energy to customers. Nevertheless, reactive power loss is obviously not less important. This is due to the fact that reactive power flow in the system needs to be maintained at a certain amount for sufficient voltage level. Consequently, reactive power makes it possible to transfer real power through transmission and distribution lines to customers. System loss reduction by strategically placed DG along the network feeder can be very useful if the decision maker is committed to reduce losses and to improve network performance (e.g. on the level of losses and/or reliability) maintaining investments to a reasonable low level [2]. This feature may be very useful in case of revenue recovered by distribution company (DISCO) which is not only based on the asset value but also on network performance. Studies indicate that poor selection of location and size of a DG in a distribution system would lead to higher losses than the losses without DG [3a, 3b].

Distribution Systems Voltage Profile Improvement

In a power system, the system operator is obligated to maintain voltage level of each customer bus within the required limit. To ensure voltage profiles are satisfactory in distribution systems, different standards have been established to provide stipulations or recommendations. For example, the American National Standards Institute (ANSI) standard C84.1 has stipulated that voltage variations in a distribution system should be controlled within the range of -13% to 7% [4]. Actually in practice, many electricity companies try to control voltage variations within the range of ±6%. One of the upcoming widely adopted methods for improving voltage profiles of distribution systems is introducing distributed generation (DG) in distribution systems. The DG units improve voltage profiles by changing power flow patterns. The locations and size of DGs would have a significant impact on the effect of voltage profile enhancement.

Distributed Generation placement and sizing

Distributed generation (DG) is small-scale power generation that is usually connected to distribution system. The Electric Power Research Institute (EPRI) defines DG as generation from a few kilowatts up to 50MW [5]. Ackermann *et al.* have given the most recent definition of DG as: “DG is an electric power generation source connected directly to the distribution network or on the customer side of the meter.” [6]. The DG when connected to network can provide a number of benefits. Some of the benefits are power losses reduction, energy undelivered costs reduction, preventing or delaying network expansion [7, 8]. Other benefits are peak load operating costs reduction, improved voltage profile and improved load factor [9]. Other than providing benefits, DG can also have negative impacts on network. These impacts include frequency deviation, voltage deviation and harmonics on network [10]. The increase of power losses is another effect that may occur [7, 11]. Thus careful considerations need to be taken when sizing and locating DGs in distribution systems.

Usually, DGs are integrated with the existing distribution system and lots of studies are done to find out the best location and size of DGs to produce utmost benefits. The main characteristics that are considered for the identification of an optimal DG location and size are the minimization of transmission loss, maximization of supply reliability and maximization of profit of the distribution companies (DISCOs). Due to extensive costs, the DGs should be allocated properly with optimal size to enhance the system performance in order to minimize the system loss as well as to get some improvements in the voltage profile while maintaining the stability of the system. The effect of placing a DG on network indices usually differs on the basis of its type, location and load at the connection point [12]. Thus interconnection planning of DG to electrical network must consider a number of factors. The factors include DG technology; capacity of DG unit; location of DG connected and network connection type [7, 11].

In EI-hattam and Salma [13], an analytical approach has been presented to identify appropriate location to place single DG in radial as well as loop systems to minimize losses. But, in this approach, optimal sizing is not considered. Loss Sensitivity Factor method (LSF) applied by Graham *et al*., [14] is based on the principle of linearization of the original nonlinear equation (loss equation) around the initial operating point, which helps to reduce the amount of solution space. Optimal placement of DG units is determined exclusively for the various distributed load profiles to minimize the total losses. Ashwani Kumar and Wenzhong Gao [15] presented a multi-objective optimization approach for determining optimal location of DGs in deregulated electricity markets with a aim of improving the voltage profile and reducing the line losses. This approach combined the use of power flow and power loss sensitivity factors in identifying the most suitable zone and then optimized the solution by maximizing the voltage improvement and minimizing the line losses in the network. This work did not consider reactive power loss in optimization.

T. N. Shukla, S.P. Singh and K. B Naik (2010) [2] used GA to optimally locate DG for minimum system losses in radial distribution networks. The appropriate location is decided on the basis of active power loss sensitivity to real power injection through DG. They demonstrated that the benefit increases with increased number of locations within certain locations beyond which it is uneconomical. This formulation considered active power losses only. The Genetic Algorithm (GA) based method to determine size and location of DG unit was also used in Ault and McDonald (2000) and Caisheng and Nehrir (2004) [16, 17]. They addressed the problem in terms of cost, considering that cost function may lead to deviation of exact size of the DG unit at suitable location. J. J. Jamian and others (2012) [18] implemented an Evolutionary PSO for sizing DGs to achieve power loss reduction. They argued that though EPSO and PSO give same performance in finding the optimal size of DG, EPSO can give superior results by having less iteration and shorter computation time. Besides that, EPSO avoids the problem of being trapped in a local minimum by selecting the survival particles to remain in the next iteration. Yustra, Mochamad Ashari and Adi Soeprijanto (2012) [19] proposed a method based on Improved PSO (IPSO) for optimal DG allocation with the aim of reducing system losses. IPSO generated more optimal solution than PSO and SGA methods using active power losses reduction parameter. However, IPSO method needed more iteration to converge compared to the other two methods. M. Vatankhah and S.M. Hosseini (2012) [20] proposed the use of new coding in PSO which included both active and reactive powers of DGs to achieve better profile improvement by optimizing the size and location of the DGs. In their proposed method, four set of weighing factors are chosen based on the importance and criticality of the different loads. Their results showed that the weighting factor had a considerable effect on voltage profile improvement. Arash Afraz and others (2012) [21] also proposed a PSO based approach to optimize the sizing and sitting of DGs in radial distribution systems with an objective of reducing line losses and improving voltage profile. The proposed objective function was a multi-objective one considering active and reactive power losses of the system and the voltage profile. In their research they considered a DG generating active power only.

S. Chandrashekhar Reddy, P. V. N. Prasad and A. Jaya Laxmi (2012) [12], proposed a hybrid technique which includes genetic algorithm (GA) and neural network (NN) for identification of possible locations for fixing DGs and the amount of power to be generated by the DG to achieve power quality improvement. They argued that by fixing DGs at suitable locations and evaluating generating power based on the load conditions, the power quality of a system can be improved. In this work only real power loss was considered. M. Abedini and H. Saremi (2012) [22] presented a combination of GA and PSO for optimal DG location and sizing in distribution systems with load uncertainty. The combined method was implemented for the 52 bus system to minimize real power losses and increase voltage stability. The proposed method was found to produce better results compared to either of the two methods. They optimized the location and size of a DG generating active power only. In their work J. K. Charles et al. (2013) [23] presented a GA-IPSO based approach for optimizing the size and location of a DG in power system network with the aim of reducing system losses and improving voltage profile. Though this method was quite successful the research work considered the location of a single DG generating active power only.

FORMULATIONS

Power flow sensitivity factors

The real and reactive power flow in a line *l* connecting two buses, bus *i* and bus *j* can be expressed as:

$$P_{ij} = V_i V_j Y_{ij}\cos(\theta_{ij}+\delta_{ij}) - V_i^2 Y_{ij}\cos\theta_{ij}$$

$$Q_{ij} = -V_i V_j Y_{ij}\sin(\theta_{ij}+\delta_{ij}) + V_i^2 Y_{ij}\sin\theta_{ij} - \frac{V_i^2 Y_{sh}}{2}$$

From these equations the power flow sensitivity factors can be evaluated using;

$$\begin{bmatrix}\frac{\partial P_{ij}}{\partial P_n}\\ \frac{\partial P_{ij}}{\partial Q_n}\end{bmatrix} = \begin{bmatrix}F_{P-P}\\ F_{P-Q}\end{bmatrix} = \left[J^T\right]^{-1}\begin{bmatrix}\frac{\partial P_{ij}}{\partial \delta}\\ \frac{\partial P_{ij}}{\partial V}\end{bmatrix} \qquad \begin{bmatrix}\frac{\partial Q_{ij}}{\partial P_n}\\ \frac{\partial Q_{ij}}{\partial Q_n}\end{bmatrix} = \begin{bmatrix}F_{Q-P}\\ F_{Q-Q}\end{bmatrix} = \left[J^T\right]^{-1}\begin{bmatrix}\frac{\partial Q_{ij}}{\partial \delta}\\ \frac{\partial Q_{ij}}{\partial V}\end{bmatrix}$$

Power loss sensitivity factors

The real and reactive power losses in a line *k* connecting two buses, bus *i* and bus *j* can be expressed as;

$$P_{L(ij)} = g_{ij}(V_i^2 + V_j^2 - 2V_i V_j \cos\delta_{ij})$$

$$Q_{L(ij)} = -b_{ij}^{sh}(V_i^2 + V_j^2) - b_{ij}(V_i^2 + V_j^2 - 2V_i V_j \cos\delta_{ij})$$

From these equations the power flow sensitivity factors can be evaluated using;

$$\begin{bmatrix}\frac{\partial P_{L(ij)}}{\partial P_n}\\ \frac{\partial P_{L(ij)}}{\partial Q_n}\end{bmatrix} = \begin{bmatrix}S_{P-P}\\ S_{P-Q}\end{bmatrix} = \left[J^T\right]^{-1}\begin{bmatrix}\frac{\partial P_{L(ij)}}{\partial \theta}\\ \frac{\partial P_{L(ij)}}{\partial V}\end{bmatrix} \qquad \begin{bmatrix}\frac{\partial Q_{L(ij)}}{\partial P_n}\\ \frac{\partial Q_{L(ij)}}{\partial Q_n}\end{bmatrix} = \begin{bmatrix}S_{Q-P}\\ S_{Q-Q}\end{bmatrix} = \left[J^T\right]^{-1}\begin{bmatrix}\frac{\partial Q_{L(ij)}}{\partial \theta}\\ \frac{\partial Q_{L(ij)}}{\partial V}\end{bmatrix}$$

The combined sensitivity factor of each bus is obtained as follows;

$$CSF_i = (F_{P-Pi} \times F_{Q-Pi}) + (F_{P-Qi} \times F_{Q-Qi}) + (S_{P-Pi} \times S_{Q-Pi}) + (S_{P-Qi} \times S_{Q-Qi})$$

Multi-objective function

The multi-objective index for the performance calculation of distribution systems for DG size and location planning considers the below mentioned indices by giving a weight to each index.

Real power loss reduction index

Real Power Loss Reduction Index (PLRI) is expressed as:

$$PLRI = \frac{P_{L(base)} - P_{L(DGi)}}{P_{L(base)}}$$

Reactive power loss reduction index

Reactive Power Loss Reduction Index (QLRI) is expressed as;

$$QLRI = \frac{Q_{L(base)} - Q_{L(DGi)}}{Q_{L(base)}}$$

Voltage profile improvement index

The Voltage Profile Improvement Index (VPII) is defined as;

$$VPII = \frac{1}{\lambda + \max_{1}^{n}(|1 - V(n)|)}$$

Multi-objective based problem formulation

In order to achieve the performance calculation of distributed systems for DG size and location the Multi-Objective Function (MOF) is given by;

$$MOF = w_1 PLRI + w_2 QLRI + w_3 VPII$$

Where;

w_1 , w_2 and w_3 are the respective weights assigned to each factor.

The sum of the absolute values of the weights assigned to all the impacts should add up to one. That is;

$$|w_1| + |w_2| + |w_3| = 1$$

These weights are indicated to give the corresponding importance to each impact indices and depend on the required analysis. The weights vary according to engineer’s concerns. In this research work, more emphasizes is given to real power loss reduction since this results to a considerable decrease in total cost. Though this is not to mean that the other two factors are not important, thus the weights are assigned as follows;

$w_1 = 0.6$, $w_2 = 0.2$ and $w_3 = 0.2$

Thus the MOF is given by;

$$MOF = 0.6PLRI + 0.2QLRI + 0.2VPII$$

Operational constraints formulation

The above formulated multi-objective function is minimized subject to various operational constraints so as satisfy the electrical requirements for the distribution network.

Load balance constraint

For each bus, the following load regulations should be satisfied;

$$P_{gni} - P_{dni} - V_{ni}\sum_{j=1}^{N} V_{nj} Y_{nj} \cos(\delta_{ni} - \delta_{nj} - \theta_{nj}) = 0$$

$$Q_{gni} - Q_{dni} - V_{ni}\sum_{j=1}^{N} V_{nj} Y_{nj} \sin(\delta_{ni} - \delta_{nj} - \theta_{nj}) = 0$$

Real and reactive power generation limit

This refers to the upper and lower real and reactive power generation limit of generators at bus-i.

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max}, i = 1,2,\ldots N_g$$

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max}, i = 1,2,\ldots N_q$$

Voltage limit

The voltage must be kept within standard limits at each bus.

$$V_i^{\min} \le V_i \le V_i^{\max}, i = 1,2,\ldots. N_b$$

DG real and reactive power generation limit

This includes the upper and lower real and reactive power generation limit of distributed generators connected at bus-i.

$$P_{DGi}^{\min} \le P_{DGi} \le P_{DGi}^{\max}, i = 1,2,\ldots N_{DG}$$

$$Q_{DGi}^{\min} \le Q_{DGi} \le Q_{DGi}^{\max}, i = 1,2,\ldots N_{DG}$$

PROPOSED METHODOLOGY

The proposed GA-IPSO based approach for optimal allocation of DG units in the distribution systems is as detailed in the following implementation steps;

1. Get system data by reading the power system parameters.
2. Employ Newton-Raphson method for load flow studies to calculate system base case power loss.
3. Compute CSF for each bus and arrange buses in order of sensitivity

$$CSF_i = (F_{P-Pi} \times F_{Q-Pi}) + (F_{P-Qi} \times F_{Q-Qi}) + (S_{P-Pi} \times S_{Q-Pi}) + (S_{P-Qi} \times S_{Q-Qi})$$

4. Buses with high sensitivities are chosen as candidate buses.
5. Input both GA and IPSO control parameters.
6. Set candidate bus count $i = 1$
7. While $i \le n$

(i) Initialize N chromosomes with random values to represent possible DG sizes.
$$P_{DG}^{\min} \le P_{DGj} \le P_{DG}^{\max} \ and \ Q_{DG}^{\min} \le Q_{DGj} \le Q_{DG}^{\max},\ j = 1,2,\ldots N$$

(ii) Set iteration count (for GA) $k = 1$

(iii) While $k \le k_{\max}$

- a) Evaluate each chromosomes fitness using the multi-objective.
- b) Using roulette wheel selection method select two chromosomes (X_{p1} and X_{p2}).
- c) Perform crossover and mutation based on the probabilities P_{cross} and P_{mut}
- d) Create a new population by repeating steps (b) and (c) while accepting the newly formed children until the new population is complete.
- e) Replace old population with new population.
- f) Update the iterations counter $k = k + 1$

(iv) Stop and pass current chromosomes (partially optimized) to IPSO.

(v) Use GA optimized chromosomes as initial IPSO particles.

(vi) Calculate the fitness value for each particle using the multi-objective function. The value of each particle becomes its p_{best}. The particle value with the best fitness among all the p_{best} is denoted as q_{best}

(vii) Set iteration count (for IPSO) $iter = 1$

(viii) While $iter \le iter_{\max}$

- a) Modify the velocity of each particle element as shown.
  $$V_{id}^{iter+1} = wV_{id}^{iter} + c_1 r(P_{best_{id}} - S_{id}^{iter}) + c_2 r(G_{best_{id}} - S_{id}^{iter})$$
  Where; $w_k = w_{\max} - \dfrac{(w_{\max} - w_{\min})}{iter_{\max}}.iter$

  Then generate the new position for each particle element.
  $$S_{id}^{iter+1} = S_{id}^{iter} + V_{id}^{iter+1}$$
- b) Using greedy selection method select two chromosomes (S_{p1} and S_{p2}).
- c) Perform crossover and mutation based on the probabilities P_{cross} and P_{mut}
- d) Create a new population by repeating steps (c) and (d) while accepting the newly formed children until the new population is complete.
- e) Compute the fitness value of each new particle and update p_{best} and q_{best} as shown;
  $$p_{best(j)}^{iter+1} = \left\{ \begin{array}{l} S_{(j)}^{iter+1} \ldots\ldots\ldots.if\ MOF_j^{iter+1} \prec MOF_j^{iter} \\ p_{best(j)}^{iter} \ldots\ldots\ldots.if\ MOF_j^{iter+1} \ge MOF_j^{iter} \end{array} \right.$$
  $$q_{best}^{iter+1} = \left\{ \begin{array}{l} p_{best(j)}^{iter+1} \ldots\ldots\ldots.if\ MOF^{iter+1} \prec MOF^{iter} \\ q_{best}^{k} \ldots\ldots\ldots.if\ MOF^{iter+1} \ge MOF^{iter} \end{array} \right.$$
- f) Update the iteration counter, $iter = iter + 1$

(ix) Stop. The particle that generates the latest q_{best} is the optimal solution.

(x) With the latest q_{best} in the network calculate system power loss and bus voltages ($P_{L(DGi)}, Q_{L(DGi)} and V_{(DGi)}$).

(xi) Update the candidate bus $i = i + 1$

8. Compare the fitness of candidate buses q_{best}'s and get the most minimized one(s).
9. The results give the optimal locations and their respective optimal DG sizes.

RESULTS AND ANALYSIS

In this case the DG(s) were assumed to be located in an IEEE 30-bus test system. For comparison purposes the base case real power losses of this test system were taken as 17.9773MW as given by Yustra *et al*. in their research work which they proposed an algorithm to optimize the location and size of a multi-type DG [19]. Since the main objective of Yustra *et al.* work was to minimize real power losses they did not take into account the reactive power losses. Thus the base case reactive power losses were obtained using Newton Raphson method to be 68.8881MVAR. To ensure fair comparison the number of DGs to be optimally located and sized was maintained same with that of the work under comparison; that is four DGs.

The DG limits were taken to be as follows so as to ensure the same values during validation;

- 0MW -12MW for real power limit (Type 1, 2 and 3 DGs)
- 0MVar – 3MVar for reactive power limit (Type 2 DG)
- -3MVar – 0MVar for reactive power limit (Type 3 DG)

Results for all Candidate Buses

The combined sensitivity factors were analyzed for all the buses and the buses which gave a combined sensitivity factor of more than 0.8 were taken to be the candidate buses. So as to be able to choose the optimal location(s) of the DG(s) and their respective optimal sizes, results were obtained taking into consideration all the candidate buses. This was done for each of the three types of DG and the obtained results tabulated as follows;

Table 1: Results for CSF, Fitness and optimal DG sizes for candidate buses

Candidate Bus	Combined Sensitivity Factor (CSF)	Type 1 DG		Type 2 DG		Type 3 DG	
		Fitness	DG Size (MW)	Fitness	DG Size (MW+jMVar)	Fitness	DG Size (MW-jMVar)
10	0.8789	0.9176	11.987	0.9178	12+j2.6903	0.9176	11.9826-j0
11	0.9236	0.9198	11.981	0.9198	11.8514+j2.9983	0.9198	11.8403-j2.1163
15	0.8352	0.9165	11.506	0.9157	12+j2.5159	0.9169	12-j1.4395
17	0.8733	0.9173	11.999	0.9167	12+j2.4561	0.9173	11.6399-j0.0601
18	1.022	0.9134	11.955	0.9125	11.9865+j3	0.9149	11.9873-j2.9989
19	1.0957	0.9118	11.71	0.9109	11.7872+j2.9609	0.9118	12-j0.4882
20	1.0637	0.9133	11.588	0.9125	11.7311+j2.8894	0.9133	11.6636-j0.3807
21	0.9973	0.9128	11.994	0.9119	12+j2.5813	0.9128	11.947-j0.5042
22	1.0558	0.9169	11.988	0.9163	12+j2.7596	0.9169	11.9909-j0
23	0.9909	0.9129	11.71	0.9118	11.7548+j3	0.9129	12-j0.0886
24	1.0349	0.9123	11.996	0.9112	12+j1.3702	0.9123	11.9179-j0.0692
25	0.8743	0.9175	11.523	0.9154	11.9782+j3	0.9165	10.6418-j0.57
26	1.0064	0.9221	11.824	0.9198	11.9763+j1.5112	0.9216	11.8898-j0
30	0.811	0.9091	11.706	0.9083	11.8308+j1.5817	0.9191	11.3651-j0.5807

Table 2: A comparison of Results obtained using Type 1 DG

Methodology	Bus No.	DG Size	Power Losses		Power Loss Reduction		% Power Loss Reduction	
		MW	MW	Mvar	MW	Mvar	%MW	%Mvar
SGA[19]	10	11.472	12.3919	_	5.5853	_	31.07	_
	10	11.904						
	19	11.052						
	24	11.772						
PSO[19]	10	11.694	12.2622	_	5.7151	_	31.79	_
	15	11.394						
	20	11.378						
	30	10.577						
IPSO[19]	10	11.625	12.1851	_	5.7922	_	32.22	_
	10	11.956						
	22	11.995						
	30	11.986						
GA-IPSO (This Method)	19	11.7099	11.602	44.084	6.3753	24.8041	35.46	36.01
	21	11.9937						
	24	11.996						
	30	11.7061						

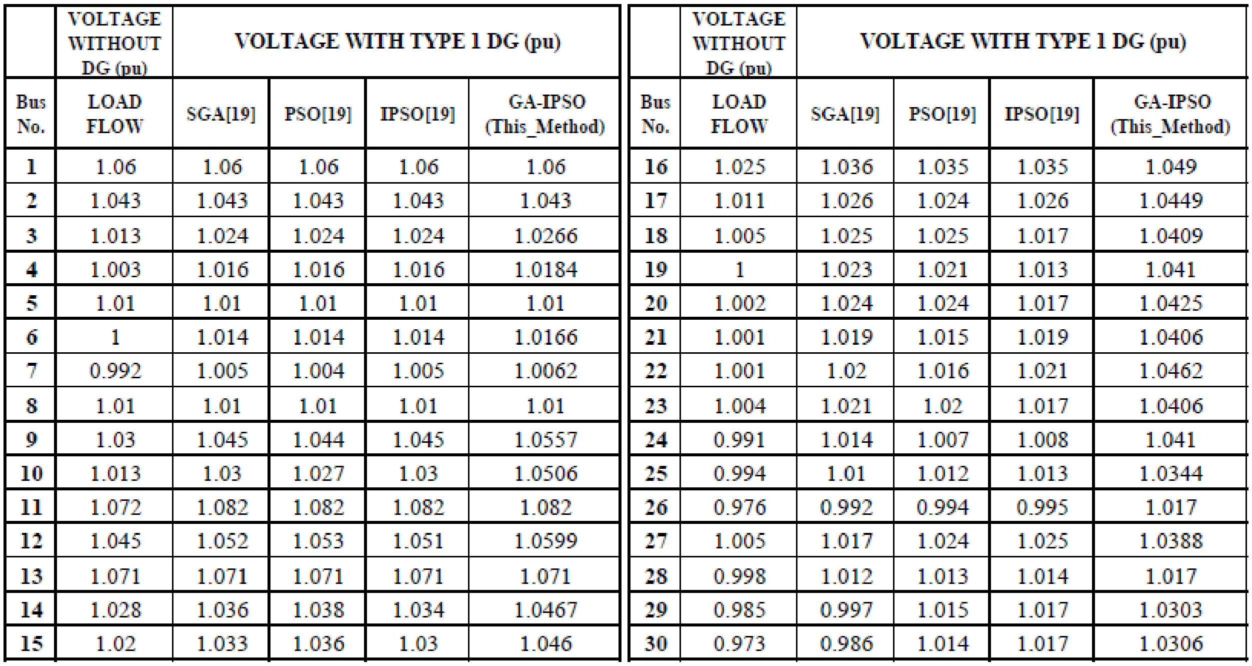
Table 3: A comparison of results obtained using Type 2 DG

Methodology	Bus No.	DG Size	Power Losses		Power Loss Reduction		% Power Loss Reduction	
		MW+jMVar	MW	Mvar	MW	Mvar	%MW	%Mvar
SGA[19]	10	11.364+j1.219	12.2258	_	5.7515	_	31.99	_
	23	11.472+j1.168						
	24	11.916+j2.037						
	30	9.816+j1.468						
PSO[19]	10	11.474+j2.159	12.1056	_	5.8717	_	32.66	_
	17	11.981+j0.919						
	20	11.67+j2.309						
	30	11.349+j3						
IPSO[19]	10	11.83+j0.001	11.945	_	6.0323	_	33.56	_
	21	11.433+j3						
	24	11.739+j3						
	30	11.995+j0.001						
GA-IPSO (This Method)	19	11.7872+j2.9609	11.538	44.126	6.4393	24.7621	35.82	35.95
	23	11.7548+j3						
	24	12+j1.3702						
	30	11.8308+j1.5817						

Table 4: A comparison of results obtained using Type 3 DG

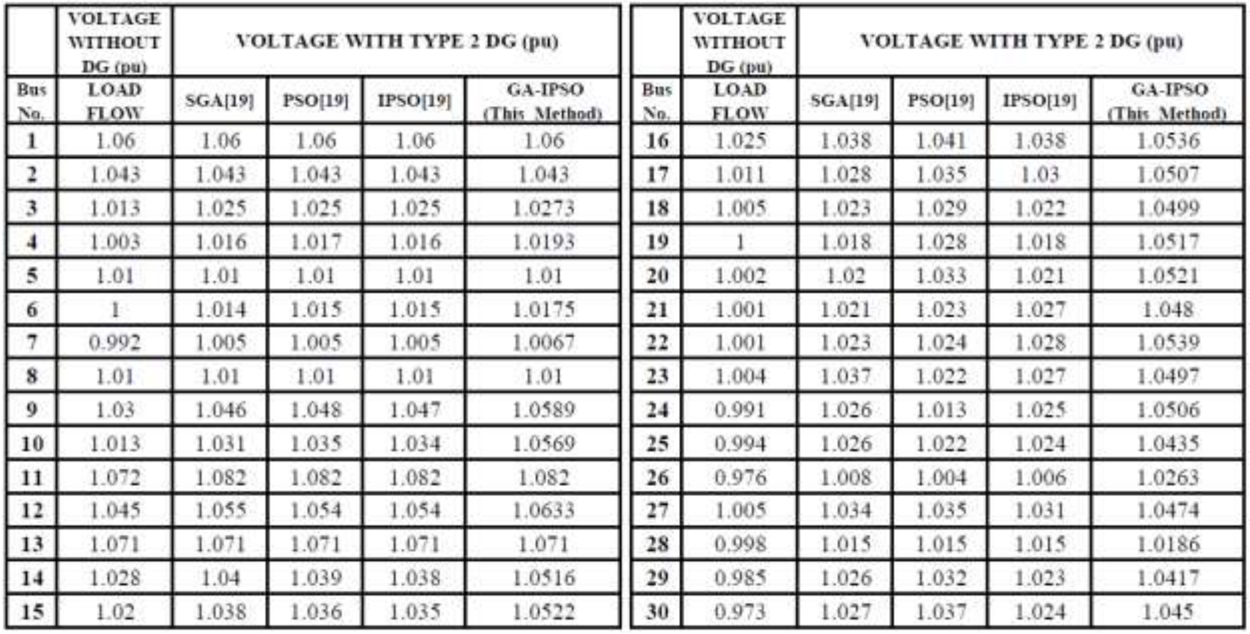
Methodology	Bus No.	DG Size	Power Losses		Power Loss Reduction		% Power Loss Reduction	
		MW-jMVar	MW	Mvar	MW	Mvar	%MW	%Mvar
SGA[19]	10	9.384-j0.088	12.5265	_	5.4509	_	30.32	_
	18	11.112-j0.715						
	22	11.748-j0.589						
	30	10.008-j0.487						
PSO[19]	10	11.885-j0.797	12.1056	_	5.6729	_	31.56	_
	18	10.881-j3						
	20	11.563-j0.899						
	30	11.35-j0.383						
IPSO[19]	10	12-j0.526	12.2099	_	5.7674	_	32.08	_
	19	10.861-j3						
	22	11.917-j2.837						
	30	11.956-j0.526						
GA-IPSO (This Method)	19	12-j0.4882	11.647	44.169	6.3303	24.7191	35.21	35.88
	21	11.947-j0.5042						
	24	11.9179-j0.0692						
	30	11.3651-j0.5807						

Table 5: A Comparison of Bus Voltages using Type 1 DG



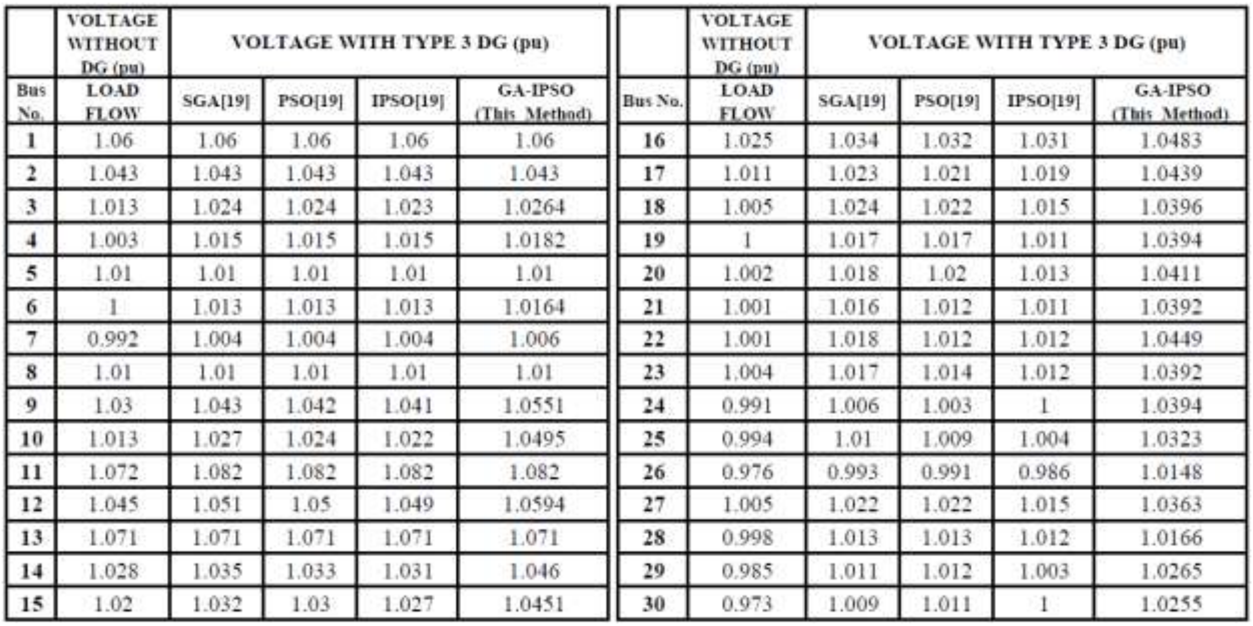
	VOLTAGE WITHOUT DG (pu)	VOLTAGE WITH TYPE 1 DG (pu)			
Bus No.	**LOAD FLOW**	**SGA[19]**	**PSO[19]**	**IPSO[19]**	**GA-IPSO (This_Method)**
1	1.06	1.06	1.06	1.06	1.06
2	1.043	1.043	1.043	1.043	1.043
3	1.013	1.024	1.024	1.024	1.0266
4	1.003	1.016	1.016	1.016	1.0184
5	1.01	1.01	1.01	1.01	1.01
6	1	1.014	1.014	1.014	1.0166
7	0.992	1.005	1.004	1.005	1.0062
8	1.01	1.01	1.01	1.01	1.01
9	1.03	1.045	1.044	1.045	1.0557
10	1.013	1.03	1.027	1.03	1.0506
11	1.072	1.082	1.082	1.082	1.082
12	1.045	1.052	1.053	1.051	1.0599
13	1.071	1.071	1.071	1.071	1.071
14	1.028	1.036	1.038	1.034	1.0467
15	1.02	1.033	1.036	1.03	1.046
16	1.025	1.036	1.035	1.035	1.049
17	1.011	1.026	1.024	1.026	1.0449
18	1.005	1.025	1.025	1.017	1.0409
19	1	1.023	1.021	1.013	1.041
20	1.002	1.024	1.024	1.017	1.0425
21	1.001	1.019	1.015	1.019	1.0406
22	1.001	1.02	1.016	1.021	1.0462
23	1.004	1.021	1.02	1.017	1.0406
24	0.991	1.014	1.007	1.008	1.041
25	0.994	1.01	1.012	1.013	1.0344
26	0.976	0.992	0.994	0.995	1.017
27	1.005	1.017	1.024	1.025	1.0388
28	0.998	1.012	1.013	1.014	1.017
29	0.985	0.997	1.015	1.017	1.0303
30	0.973	0.986	1.014	1.017	1.0306

Table 6: A Comparison of Bus Voltages using Type 2 DG



	VOLTAGE WITHOUT DG (pu)	VOLTAGE WITH TYPE 2 DG (pu)			
Bus No.	**LOAD FLOW**	**SGA[19]**	**PSO[19]**	**IPSO[19]**	**GA-IPSO (This_Method)**
1	1.06	1.06	1.06	1.06	1.06
2	1.043	1.043	1.043	1.043	1.043
3	1.013	1.025	1.025	1.025	1.0273
4	1.003	1.016	1.017	1.016	1.0193
5	1.01	1.01	1.01	1.01	1.01
6	1	1.014	1.015	1.015	1.0175
7	0.992	1.005	1.005	1.005	1.0067
8	1.01	1.01	1.01	1.01	1.01
9	1.03	1.046	1.048	1.047	1.0589
10	1.013	1.031	1.035	1.034	1.0569
11	1.072	1.082	1.082	1.082	1.082
12	1.045	1.055	1.054	1.054	1.0633
13	1.071	1.071	1.071	1.071	1.071
14	1.028	1.04	1.039	1.038	1.0516
15	1.02	1.038	1.036	1.035	1.0522
16	1.025	1.038	1.041	1.038	1.0536
17	1.011	1.028	1.035	1.03	1.0507
18	1.005	1.023	1.029	1.022	1.0499
19	1	1.018	1.028	1.018	1.0517
20	1.002	1.02	1.033	1.021	1.0521
21	1.001	1.021	1.023	1.027	1.048
22	1.001	1.023	1.024	1.028	1.0539
23	1.004	1.037	1.022	1.027	1.0497
24	0.991	1.026	1.013	1.025	1.0506
25	0.994	1.026	1.022	1.024	1.0435
26	0.976	1.008	1.004	1.006	1.0263
27	1.005	1.034	1.035	1.031	1.0474
28	0.998	1.015	1.015	1.015	1.0186
29	0.985	1.026	1.032	1.023	1.0417
30	0.973	1.027	1.037	1.024	1.045

Table 7: A Comparison of Bus Voltages using Type 3 DG



	VOLTAGE WITHOUT DG (pu)	VOLTAGE WITH TYPE 3 DG (pu)			
Bus No.	LOAD FLOW	SGA[19]	PSO[19]	IPSO[19]	GA-IPSO (This Method)
1	1.06	1.06	1.06	1.06	1.06
2	1.043	1.043	1.043	1.043	1.043
3	1.013	1.024	1.024	1.023	1.0264
4	1.003	1.015	1.015	1.015	1.0182
5	1.01	1.01	1.01	1.01	1.01
6	1	1.013	1.013	1.013	1.0164
7	0.992	1.004	1.004	1.004	1.006
8	1.01	1.01	1.01	1.01	1.01
9	1.03	1.043	1.042	1.041	1.0551
10	1.013	1.027	1.024	1.022	1.0495
11	1.072	1.082	1.082	1.082	1.082
12	1.045	1.051	1.05	1.049	1.0594
13	1.071	1.071	1.071	1.071	1.071
14	1.028	1.035	1.033	1.031	1.046
15	1.02	1.032	1.03	1.027	1.0451
16	1.025	1.034	1.032	1.031	1.0483
17	1.011	1.023	1.021	1.019	1.0439
18	1.005	1.024	1.022	1.015	1.0396
19	1	1.017	1.017	1.011	1.0394
20	1.002	1.018	1.02	1.013	1.0411
21	1.001	1.016	1.012	1.011	1.0392
22	1.001	1.018	1.012	1.012	1.0449
23	1.004	1.017	1.014	1.012	1.0392
24	0.991	1.006	1.003	1	1.0394
25	0.994	1.01	1.009	1.004	1.0323
26	0.976	0.993	0.991	0.986	1.0148
27	1.005	1.022	1.022	1.015	1.0363
28	0.998	1.013	1.013	1.012	1.0166
29	0.985	1.011	1.012	1.003	1.0265
30	0.973	1.009	1.011	1	1.0255

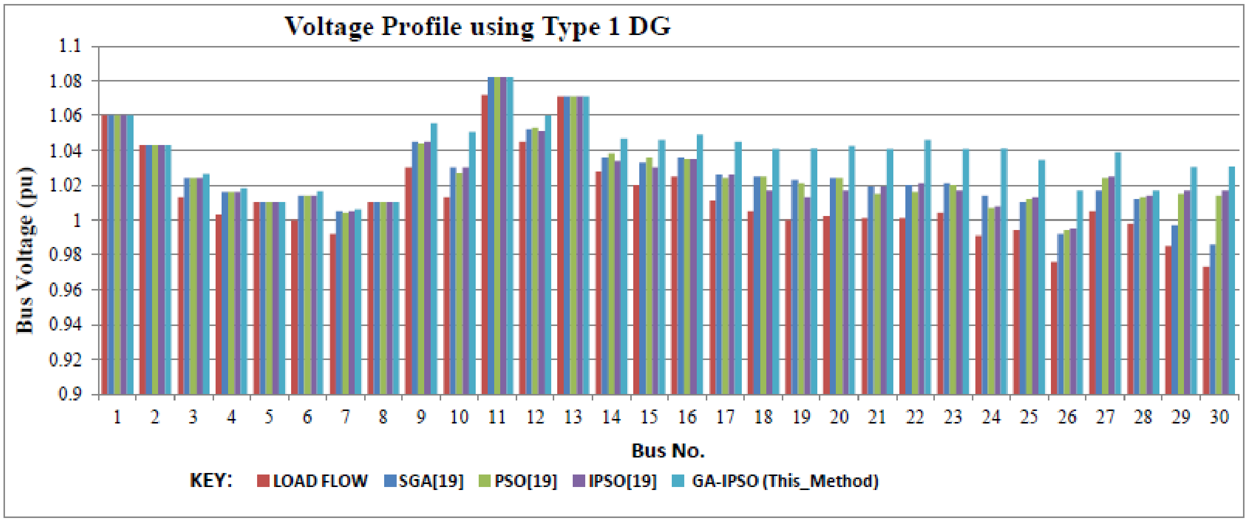


Figure 1: A figure showing bus voltage profile comparison using Type 1 DG

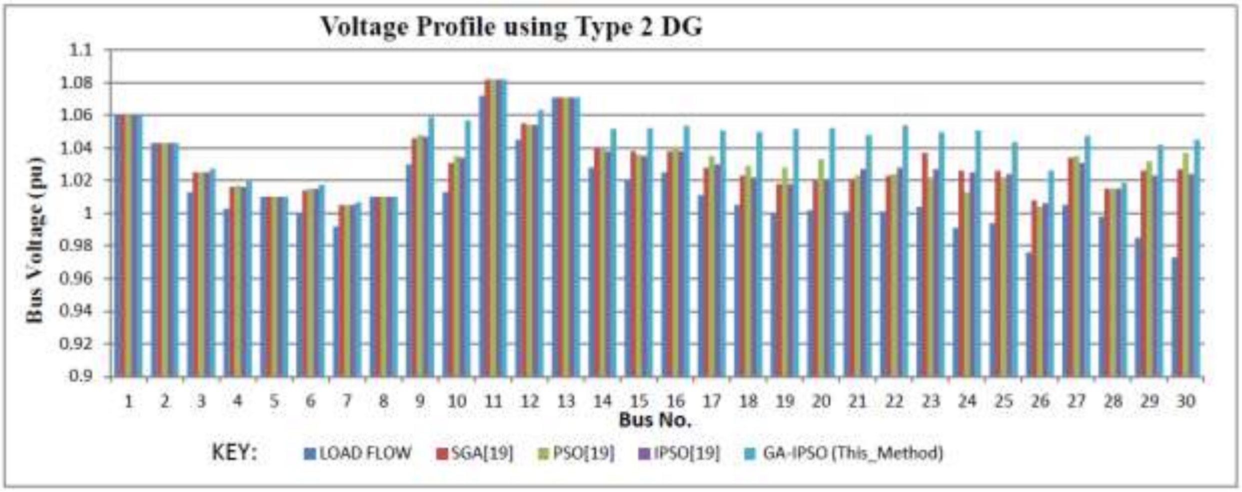


Figure 2: A figure showing bus voltage profile comparison using Type 2 DG

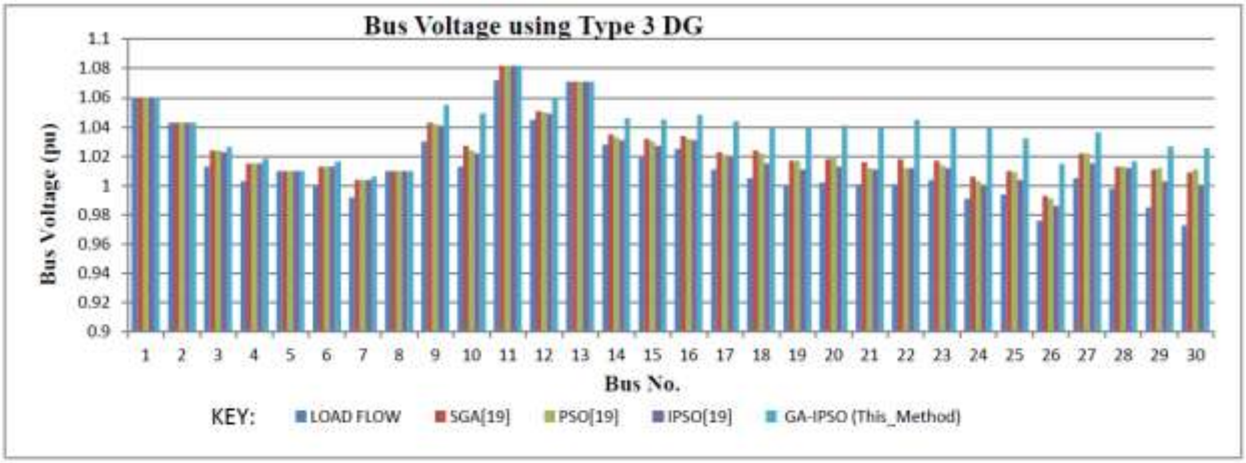


Figure 3: A figure showing bus voltage profile comparison using Type 3 DG

From the above results it can be seen clearly that the GA-IPSO method gave the greatest real power loss reduction margin as compared to the other three methodologies. The percentage real power loss reduction from this method considering type 1 DG was 35.46% compared to 32.22% for IPSO, 31.79% for PSO and 31.07% for SGA. The percentage reduction in real power losses obtained when optimizing the location and size of type 2 DG using GA-IPSO method is 35.82%. This percentage is the highest when compared to the other three methodologies; IPSO gave a reduction of 33.56%, PSO gave a reduction of 32.66% while SGA resulted to a real power reduction percentage of 31.99%. With a real power reduction percentage of 35.21% compared to IPSO's 32.08%, 31.56% from PSO and 30.32% from SGA it is with no doubt that GA-IPSO method performs best among the optimization techniques when considering type 3 DG.

Though, the reference work under comparison considered only real power losses the results of GA-IPSO method showed considerable reduction of reactive power losses in the system. The respective percentage reductions in reactive power losses were as follows; 36.01% for type 1 DG, 35.95% for type 2 DG and 35.88% for type 3 DG. It is also important to note that the sizes of DGs obtained using GA-IPSO method compared well to the sizes from the other methods. Therefore the GA-IPSO method is seen to be superior to the other three methods in terms of optimizing the location and size of a multi-type DG with the objective of reducing system power losses. Although the voltages of an ideal IEEE 30-bus test system are within the acceptable ranges that is 0.95pu to 1.1pu, the inclusion of a DG can affect this voltage stability. From the results shown above it can be seen that the inclusion of the DGs does not result to deviation of voltage levels outside the acceptable limits. As it is evident all the bus voltages were in the range of 1.0pu to 1.1pu. Thus the GA-IPSO method improved the voltage levels of those buses which had voltages of less than 1.0pu to at least 1.01pu while ensuring that no voltage level rises above the acceptable limit. As a matter of fact this method maintained the highest bus voltage value at 1.082pu.

CONCLUSION

This paper gives the formulation and implementation of a GA/IPSO based algorithm for system loss reduction and voltage profile improvement in distribution systems by optimal location and sizing of a DG. Combined sensitivity factors were effectively utilized to come up with the candidate locations for DGs. The algorithm proposed has resulted to better results in terms of both real and reactive power loss reduction and voltage profile improvement as compared to SGA, PSO and IPSO methods. Arithmetic crossover and mutation was employed in this methodology enabling the use of real coded GA chromosomes and PSO particles. GA algorithm was used for the first less iterations so as to utilize its advantage of exploring fast regions and avoid its disadvantage of lower convergence. The results of GA were used to initialize PSO particles so as to increase its convergence rate. Both crossover and mutation operators were also employed in improving the PSO. This ensured that the disadvantage of premature convergence for PSO is avoided.

As a result of utilizing the merits of these two optimization techniques while trying to avoid their demerits the proposed methodology resulted to a real power loss reduction of 35.46%, 35.82% and 35.21% for Type 1, 2 and 3 DGs respectively. On the other hand the reactive power losses were reduced by 36.01% for Type 1 DG, 35.95% for Type 2 DG and 35.88% for Type 3 DG. In addition the lowest bus voltage was improved from 0.973pu to 1.01pu while maintaining the highest voltage level at 1.082pu.

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