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Application of Metaheuristic Algorithms for Optimal Allocation of DGs in Radial Distribution System

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***Abstract* - Metaheuristic algorithms form an important part of an area of Artificial Intelligence (AI). These algorithms are being used to find optimal solutions to a variety of problems in electrical engineering such as allocation of Distributed Generation (DG), coordination of relays, unit commitment etc. This paper presents the application of AI-based optimization algorithms to find the optimal location and sizing of DG in the radial distribution system (RDS). The problem is formulated to minimize real power loss and improve voltage stability in RDS and it is solved using metaheuristic algorithms viz. Particle Swarm Optimization algorithm (PSO), Modified teaching learning-based optimization algorithm (MTLBO) and Jaya algorithm. The results obtained using these algorithms are also compared with those obtained with the conventional analytical method. IEEE 33-bus RDS is considered as a test system. Simulation studies were carried out using MATLAB software. The novel feature of the paper is the application of recent Jaya algorithm to the optimization problem.**

Keywords: Artificial Intelligence, DG, Jaya algorithm, Metaheuristic algorithm, MTLBO, Optimization, PSO, RDS.

I. INTRODUCTION

Metaheuristic algorithms are considered as higher level procedures in computer science. These are used to provide solutions to optimization problems. There are two types of metaheuristic algorithms: population based and trajectory based. This paper has made use of three population based algorithms. These algorithms have found applications in diverse fields. One such field is power distribution system.

In intelligent power system, DG technologies play an essential role in distribution system. According to International Energy Agency, DG is an electric power source connected directly to distribution network or on the customer side of the meter. Integrating DGs in distribution system causes economic, technical and environmental benefits. Economical aspects include the price of energy, investment, operating cost of DG and the cost of losses.

Technical aspects include energy losses and voltage levels. Renewable energy source based DG technologies includes wind, solar, small hydro, geothermal, biomass, etc. Whereas fuel cells, combustion turbines and internal combustion engines comes under fuel based DG sources.

As energy demand increases, the possibilities of voltage collapse will increase proportionally in power system. The problem of identifying the nodes close to voltage collapse in distribution systems has attracted much attention. Location and sizing of DG plays a crucial role in obtaining maximum DG benefits. The benefits of DG integration include voltage profile, losses, stability and reliability issues. Inappropriate location and sizing of DG in distribution system may lead to negative impacts.

Many researchers have been implementing various algorithms to find the adequate location and size of DGs to exploit the DG integration benefits. Genetic Algorithm (GA) [1], PSO [2], Ant Colony [3], analytical method [4], Artificial Bee Colony algorithm [5], Differential Evolution [6] and Cuckoo Search algorithm [7] are some of the algorithms that were used to solve the given optimization problem. Algorithms are combined (GA-PSO, fuzzy-GA, fuzzy-PSO., etc.) [8]-[9] with a claim to have achieved better results. R.V. Rao et al. [10] introduced a teaching learning based optimization algorithm to solve an optimization problem. This algorithm correlates to a teacher with students learning in a classroom. J.A. Maetin Garcia et al. [11] applied MTLBO technique for the optimal placement of DGs in RDS.

In this paper, the recently proposed Jaya algorithm [12]

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is used for solving the optimization problem in addition to other algorithms. The results obtained show the efficacy of the metaheuristic algorithms.

II. PROBLEM FORMULATION

In this section, the multi objective function for the analysis of distribution network with DG units is presented. The objective of optimization problem considered is to minimize total real power loss and maximize voltage stability index (VSI). Each individual objective function is given a weighting factor (w1 and w2) based on their relative importance with respect to each other.

In this paper, Backward/Forward Sweep algorithm [13] has been utilized to compute power flow in RDS. Two matrices BIBC and BCBV are used to obtain load flow solution.

The Bus-Injection to Branch-Current Matrix (BIBC) is used to compute branch currents as given below:

$$[B] = [BIBC]\,[I] \tag{1}$$

The Branch-Current to Bus-Voltage matrix (BCBV) is used to update bus voltages as follows.

$$[\Delta V] = [BCBV]\,[B] \tag{2}$$

where, [B] & [I] represents branch currents and load current matrix respectively. By multiplying these two matrices, the load flow solution is obtained.

Equation (2) can be written as,

$$[\Delta V] = [BCBV]\,[BIBC]\,[I] \tag{3}$$

where, [ΔV] matrix represents change in voltage between nodes.

The solution for the distribution load flow can be obtained by solving above equation iteratively till $\Delta V_{max} < \epsilon$ (ϵ=0.0001). This method of load flow is efficient and robust compared to conventional methods.

The mathematical expression of multi objective function is expressed as:

$$\text{Minimize} \quad f = w_1 f_1 + w_2 f_2 \tag{4}$$

$$\text{And} \qquad \sum_{i=1}^{2} w_i = 1.0 \quad \forall\; w_i \in [0,1] \tag{5}$$

where, f1 and f2 are the objective functions considered for real power loss minimization and VSI respectively.

A. Real power loss

Among all the benefits of DG integration in RDS, real power loss reduction is given much importance. In this paper, the weightage (w1) considered for real power loss is 0.6. Mathematically expression for minimizing real power loss is written as [5]:

$$\text{Minimize } f_1 = \sum_{i=0}^{n} \left(\frac{p_i^2 + q_i^2}{v_i^2} \right) \times r_{i+1} \tag{6}$$

where i=0, 1, 2,…., n, (no. of buses), pi & qi are the real and reactive power flow from ith to (i+1)th bus respectively. ri+1 represents line resistance between ith and (i+1)th line.

B. Voltage stability index

In distribution system, reaching the maximum permissible load above which load flow solution no longer exists is considered as voltage stability problem. Sudden voltage collapse in system can be attributed to low value of VSI at a particular bus. Integrating DG will maximize the VSI. In this study, the weightage (w1) of 0.4 is considered for real power loss. The branch representation of RDS is shown in Fig.1.

The mathematical expression to identify the critical buses of the system is given below [14]:

$$\mathrm{VSI}(ni) = |V_{mi}|^2 - 4[P_{ni}(ni)R_{ni} + Q_{ni}(ni)X_{ni}]|V_{mi}|^2 - 4[P_{ni}(ni)R_{ni} + Q_{ni}(ni)X_{ni}]^2 \tag{7}$$

where P_{ni}(ni) is the total real power fed through bus ni, Q_{ni}(ni) is the total reactive power load through bus ni, $R_{ni}$is the resistance of branch i, $X_{ni}$is the reactance of branch i and SI(ni) is the VSI of node.

The second objective function (f_2) considered in this paper is expressed as:

$$Minimize\ f_2 = \frac{1}{(VSI(ni))} \qquad n_i = 2, 3, \ldots, n_n \tag{8}$$

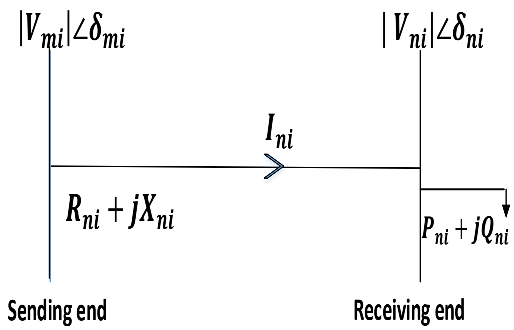

Fig.1. A representative branch of RDS.

RDS is said to be in stable operation if VSI (ni) ≥ 0. Low value of VSI of a bus represents as weak bus, which leads to system voltage collapse. To improve the system voltage stability, maximum value of VSI (ni) leads to minimum value of f_2.

C. Constraints

Voltage constraints:

$|V_{min}| \le |V_i| \le |V_{max}|$

where, V_{min} *and* V_{max} are minimum and maximum voltage limits at bus 'i'.

DG constraints:

$P_{DGn}^{min} \le P_{DGn} \le P_{DGn}^{max}, \ \forall_{n,}\, n = \{1,2,3,\dots,N\}$

where P_{DGn} is the real power supplied by DG and 'N' is the number of DGs.

III. OPTIMAL LOCATION AND SIZING OF DG

A. Analytical method

In this analytical method, Backward/Forward Sweep load flow was carried out two times, one for the base case and another with the DG integration with RDS to obtain the final solution. The real power loss of base case was taken as initial real power loss for the case with DG integration in RDS. DG of size varying from minimum to maximum value step-by-step is placed at each bus and the real power losses in the system were calculated for each case. The bus in the case with minimum power losses was considered as the optimum location and the size of the DG in corresponding case was taken as the optimum size.

B. Particle Swarm Optimization

In 1995, this nature inspired optimization technique based on the behaviour of fishes and birds was proposed by Kennedy and Eberhart. In PSO, each particle align to its best location according to its own experience so far (called P_best), and according to the overall best position achieved so far by neighbouring particle (called G_best). Improper specification of algorithm parameters like inertia weight and c_1 and c_2 have impact on convergence of the optimal solution. The ith particles modify their velocity and position until optimal solution is obtained as per the following equations.

$$V_{i+1} = \omega V_i + c_1 r_1 (P_{best} - x_i) + c_2 r_2 (G_{best} - x_i) \qquad (9)$$

$$x_{i+1} = V_{i+1} + x_i \qquad (10)$$

where c_1 and c_2 are acceleration constants, ω is the inertia weight, r_1 *and* r_2 are random values ranging between 0 and 1. V_i *and* V_{i+1} refer to current velocity and modified velocity respectively. x_i *and* x_{i+1} refer to current position and modified position respectively [8].

C. Modified teaching and learning based optimization

MTLBO algorithm correlates the teacher with students learning in a classroom. This algorithm does not require parameters as in GA (mutation, crossover) and PSO (C1, C2, ω). MTLBO is modelled into three phases, called 'Teacher phase', 'Learner phase' and 'Mutation phase'. The teacher phases consist of learners learning from the teacher and the learner phase comprises of learning via interaction between learners and in mutation phase, each learner has been modified to a new modified student (learner) [10]-[11].

D. Jaya algorithm

A new optimization technique named as 'Jaya algorithm' was proposed by R.V. Rao in 2016 [12]. This algorithm was proposed to solve unconstrained and constraints optimization problems. This algorithm does not require any specific parameters as in GA (selection, crossover, mutation) and PSO (C1, C2, ω). The principle of this algorithm is based on the movement of the obtained solution towards best solution and away from the worst solution. Jaya algorithm utilizes both best and worst solutions. Fig.2 illustrates flowchart of the Jaya algorithm. Jaya algorithm is described below.

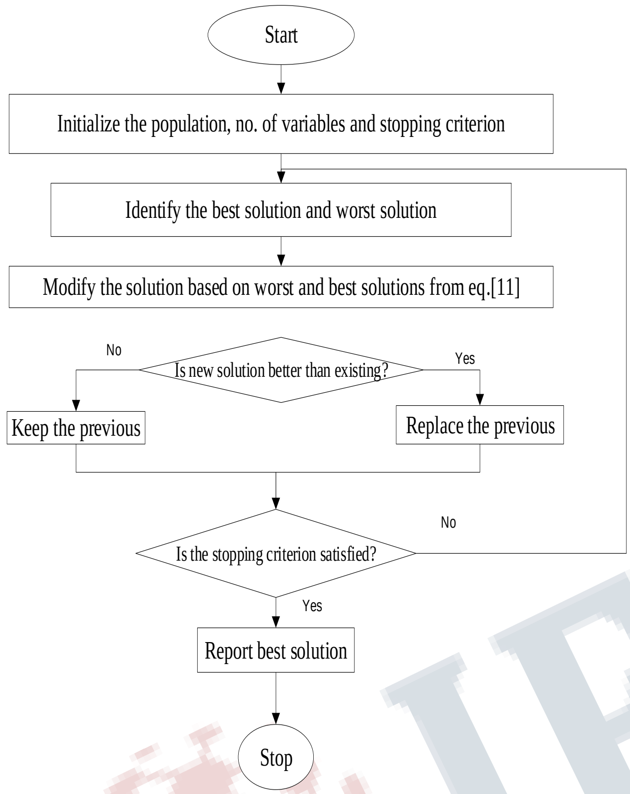

Fig.2. Flowchart for Jaya algorithm

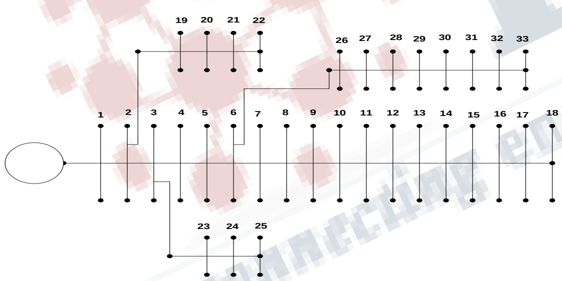

Fig.3. IEEE 33-bus RDS

In the problem of optimization of a function, consider total number of design variables as 'p'. There are 'q' numbers of candidate solutions during ith iteration. The value of jth variable for kth candidate is modified as given below.

$$X'_{j,k,i} = X_{j,k,i} + r_{1,j,i}\left[\left(X_{j,best,i}\right) - \left|X_{j,k,i}\right|\right] - r_{2,j,i}\left[\left(X_{j,worst,i}\right) - \left|X_{j,k,i}\right|\right] \quad (11)$$

where, $X_{j,best,i}$ & $X_{j,worst,i}$ are the values of the variable j for the best & worst candidate solution in the ith iteration. $X'_{j,k,i}$ is the modified solution value $r_{1,j,k,i}$&$r_{2,j,k,i}$ are random values [i.e. (0,1)] for jth variable in ith iteration. The propensity of the solution to go towards the best one is shown by second term of eq.(11). Similarly, propensity of the solution to go away from the worst one is shown by third term of equation (11).

IV. NUMERICAL RESULTS AND DISCUSSION

The codes of analytical method as well as AI algorithms viz. PSO, MTLBO, Jaya algorithm are written in MATLAB software. These algorithms are applied to the problem of finding optimal allocation and sizing of DG and tested on IEEE 33-bus test system to evaluate their effectiveness. The test system as shown in figure 3 has a total load of 3.72 MW, 2.3 MVAr. The real power loss of the test system is 211.08 kW while the reactive power loss is at 143 KVAr when calculated using load flow method. The values of parameters for Jaya & MTLBO algorithm are given below. For both methods, the population size of 40 and maximum iterations of 20 are considered. The values of parameters for PSO are c1=0.9, c2=0.9 & ω=0.1 to 0.8, population size of 150 and maximum of 100 iterations.

For the test case study, the number of DGs considered is three and size of the DG units taken is between 0.1 MW and 2MW. In this study DGs are assumed to be operated at unity power factor. The results obtained from Jaya algorithm are compared with analytical method, PSO and MTLBO technique.

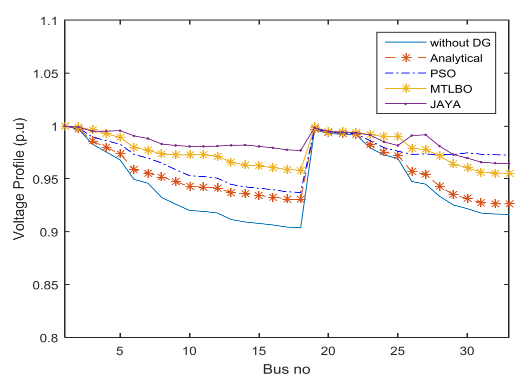

Fig.4. Voltage profile at all nodes of the 33-bus RDS

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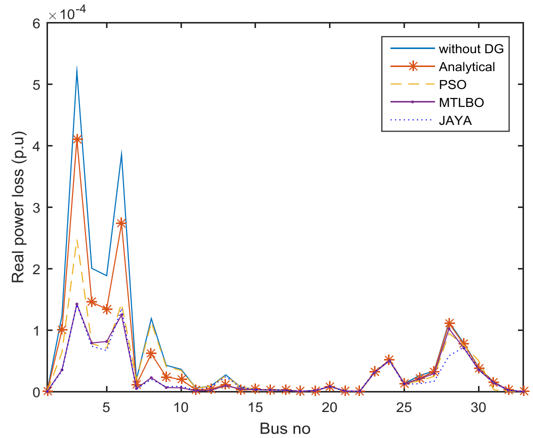

Fig.5. Graph of real power loss for 33-bus RDS

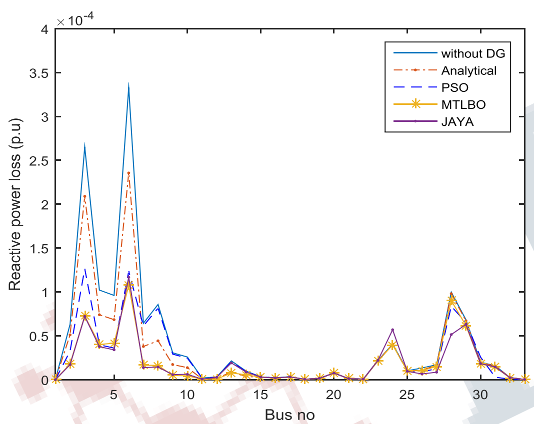

Fig.6. Graph of reactive power loss for 33-bus RDS

Table I. Results with IEEE 33-bus system with 3 DGs

Methods	Real power loss (KW)	Reactive power loss (KVAr)	Voltage stability index (p.u)	Bus no.	DG size (MW)
Analytical	161.42	108.74	1.0325	8	0.1
				14	0.2
				26	0.19
PSO	123.84	87.9	1.08225	30	1.1195
				32	0.2701
				31	0.1503
MTLBO	90.81	64	1.16225	27	1.7448
				5	0.7228
				14	0.9637
JAYA	88.10	62.02	1.1646	11	0.8152
				28	0.7439
				24	1.9044

Improvement in the voltage profile at various buses of test system obtained with four algorithms is shown in Figure 4 in comparison with voltage profile when DG is not present in the system. It can be observed that Jaya algorithm gives better voltage profile. Figure 5 shows the real power losses in the system at various buses. Similarly, Figure 6 shows the reactive power losses in the system at various buses. The active and reactive power losses are better minimized with the use of Jaya algorithm. Table 1 shows the comparison of the results obtained using four algorithms. It can be observed that with Jaya algorithm real power loss is reduced by 45.42%, 28.85% and 3% compared to analytical, PSO and MTLBO respectively for optimal location and sizing of DGs in RDS. Similarly, VSI is improved by 11%, 7.07% and 0.2% compared to analytical, PSO and MTLBO methods respectively.

CONCLUSION

There is no single AI based optimization algorithm which is capable of providing best results to variety of optimization problems. In this paper, solution to the problem of finding the optimal location and sizing of DG in RDS is presented. The paper focuses on finding the best possible metaheuristic algorithm for the purpose. The systematic procedure is adopted to formulate the problem as minimization of multi-objective function. It aims to reduce power losses and improve voltage stability. The system performance in terms of improved voltage profile and reduced reactive power loss is also observed. The results obtained using PSO, MTLBO, Jaya algorithms are compared with those obtained with conventional non-AI based method. The promising results are obtained with the recently introduced Jaya algorithm.

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