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Optimally Allocation of Distributed Generators in Three-Phase Unbalanced Distribution Network

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Abstract

Increasing energy demand can be compensated with integration of distributed energy resources in the three-phase distribution system. Load flow analysis of the unbalanced three-phase distribution system requires a tool and algorithm to manage the multiple sources. In this study, Jaya algorithm is applied and interfaced with open source software openDSS to solve the unbalanced three-phase optimal power flow. Further, co-simulation framework is used to obtain the optimal allocation of two types of multiple distributed generators in unbalanced radial distribution system. The effectiveness of the approach is validated on IEEE 123 node distribution system. For a realistic study, mixes of all type of loads and configuration of the actual distribution system are considered. The results are compared with already published results obtained from established particle swarm optimization.

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Keywords: Distributed generator; Jaya algorithm; openDSS; multi- phase unbalanced distribution system; component object model server.

1. Introduction

The electric power system has witnessed many rectifications in the last two decades. The existing conventional power systems are causing several types of problems such as high amount of emissions, voltage deviations, static-, dynamic-, and transient-stability problems, overloaded lines, service interruptions, high capital cost, and high levels

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of resistive losses [1]. Moreover, regulatory commission addresses on global warming issues with the objective to reduce the pollutants contents in the environment by decreasing the percentage of fossil fuels from the power station and increase the penetration of distributed generator (DGs) in the distribution system [2]. Moreover, DGs has contributed in the diversification of energy resources to reduce the cost and losses of transmission and distribution, decrease the operating cost of peak load, supports for uncertainty in the electricity market and competitive policies, enhances the energy security, and increases the potential for service quality [3]. Therefore, it is required to increase the percentage contribution of the DGs into the radial distribution system. However, the non-optimal allocation (site and size) of the DGs may increase the power losses of the distribution network [4]. Further, planning of DGs is essential to enhance the performance of the distribution system.

In [5]-[13], the DGs allocation was carried out utilizing different algorithms for minimizing power loss in the radial distribution system. Hung et al. [5] suggested analytical method for optimal allocation of the DER unit to minimize power loss. Singh et al. [6] modified PSO has considered to place the DGs at different penetration levels to reduce the losses of the distribution system. Elazim et al. [7] proposed a flower pollination optimization algorithm to solve the DGs allocation problem in large scale distribution networks. In [8] a method is applied to minimize the losses and viability analysis in electricity market scenarios. Multi-objective PSO approach is used to consider multi-objective criteria for minimizing active power loss along with the pollutants emission by optimum size of DGs in Indian distribution system [9]. Moreover, a lot of research work with several approaches and optimization methods has been used for allocation of the DGs in balance distribution system [10]. However, line of the distribution system is un-transposed. Moreover, the loads of the distribution system are unequally distributed in the whole power system. Therefore, DGs planning according to balanced distribution network is not a realistic approach.

In addition, Hegazy et al. [11] used a supervised big bang-big crunch method to minimize the annual energy losses in the unbalanced distribution systems. Supervised firefly algorithm is applied to find the optimal location and capacity of dispatchable DGs in unbalanced distribution feeders for power/energy loss minimization without violating the system constraints [12]. Samir et al. [13] used the PSO algorithm for optimal allocation of DGs in the unbalanced distribution system. In literature, artificial intelligence based heuristic algorithms have been widely practiced for planning of distributed energy resources with any type of power system constraints. However, some algorithms-specific control parameters are introduced in all heuristic based methods, which have needed tuning for achieving the global solution. Moreover, computational efforts can be increased by improper tuning of algorithms-specific control parameters. Moreover, Jaya algorithm is simple, single-phase and specific parameter-less, which is used to achieve admirable outcomes [14].

In this paper, a Jaya algorithm is used to DGs planning on environmental structure of MATLAB simulation in a co-simulation framework with OpendDSS functionality. Moreover, co-simulation environment with OpendDSS program is applied to solve the three phase power flow problem for optimal allocation of type I and type III DGs in the IEEE 123 bus three-phase unbalanced radial distribution systems. The optimal placement and sizing of DGs maximizes the energy loss while maintaining the desirable node voltage. To show the strength of the applied algorithm, simulation results are compared with a recently published article [13].

2. Problem Formulation

The optimal penetration of DGs power for optimal allocation problem is formulated to minimizing the active power losses. The benefits associated with DGs mainly depend upon how optimally they are allocated in the radial distribution system while node voltage and all constraints of the power system should be preserved in the proper boundary. Further, the aim of this object function is described as:

$$F = \max\left[\zeta\left(\sum_{p=1}^{3}\sum_{i=1}^{n_b}\mathrm{Re}\left(\left|I_i\right|^2 .R_{ij}\right)_a - \sum_{p=1}^{3}\sum_{i=1}^{n_b}\mathrm{Re}\left(\left|I_i\right|^2 .R_{ij}\right)_b\right)\right] \qquad \forall i,j \in n_b \tag{1}$$

2.1 Voltage limits at load bus and slack bus

The voltage at each bus (V_m) should lie within the specified boundaries which is five percent from the rated value according to distribution feeder regulation. The voltage magnitudes and angle of the slack bus must be one and zero, respectively, throughout the duration of DGs planning.

$$V_{\min} \le V_{m_i} \le V_{\max} \tag{2}$$

2.2 Power balance

In the network, total supply of power from the distribution grid substation (GSS) and DGs must be equal to the summation of power demand and system line losses.

$$S_{GSS} + \sum_{i=1}^{n} S_{DGs} - \sum_{i=1,\, j=j+1}^{nb} B_{ij}^{2} \cdot Z_{ij} = \sum_{i=1}^{n} S_{Dem} \tag{3}$$

2.3 Distribution line thermal limit

The current carrying capacity of the distribution line must consider as constraint because line of the network should be capable of transmitting the power with the placement of the DGs in the distribution system. Therefore, the excess power flow leads to melting of the line.

$$S_{ij,\max} \ge S_{ij} \tag{4}$$

2.4 DGs Generation

The active and reactive power of Type I and Type III DGs is considered only in the permissible operating region.

$$P_i^{\min} < P_{DGs_i} \le P_j^{\max} \tag{5}$$

$$Q_i^{\min} < Q_{SCs_i} \le Q_i^{\max} \tag{6}$$

The range of P_{DGs} and Q_{SCs} should not exceed to the comparable literature either initialization or updating process of optimization.

3. **Methodology**

A co-simulation framework has been considered to solve the optimum DG allocation problem in three-phase distribution system as shown in Fig. 1. The OpenDSS is an open source electric power Distribution System Simulator (DSS) which analyzes the integration of distributed resource and grid modernization. The functionality of the simulator is utilized through adding the looping advanced analysis and visualization abilities of MATLAB. The OpenDSS has been interfaced with MATLAB through COM (Component Object Model) Server [15]. The commands to the simulator are executed from the environmental structure of MATLAB and the results are displayed at front end system. The overall process of the proposed approach is shown in Fig. 2.

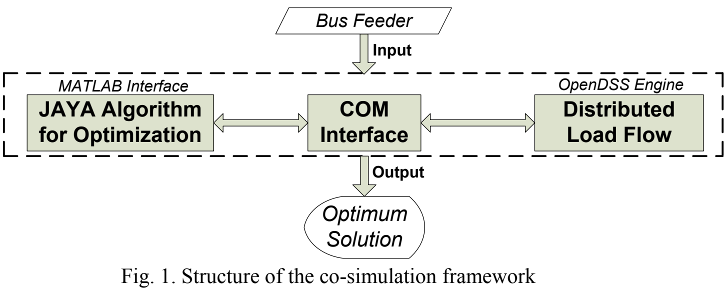

Fig. 1. Structure of the co-simulation framework

Jaya algorithm is a very robust algorithm which is proposed to obtain the global solutions with high consistency and less computational efforts by Venkata Rao [14]. A single step algorithm can be applied to solve both constrained and unconstrained optimization problem. The basic concept of the Jaya is based on the best and worst solution of objective function. This algorithm has temptation to achieve the destination in minimum time. This robust algorithm obtains the optimized solution in less computation time with better consistency.

The step-by-step process of the proposed approach is implemented to solve the optimal allocation of the DG in unbalanced distribution system with co-simulation environment following:

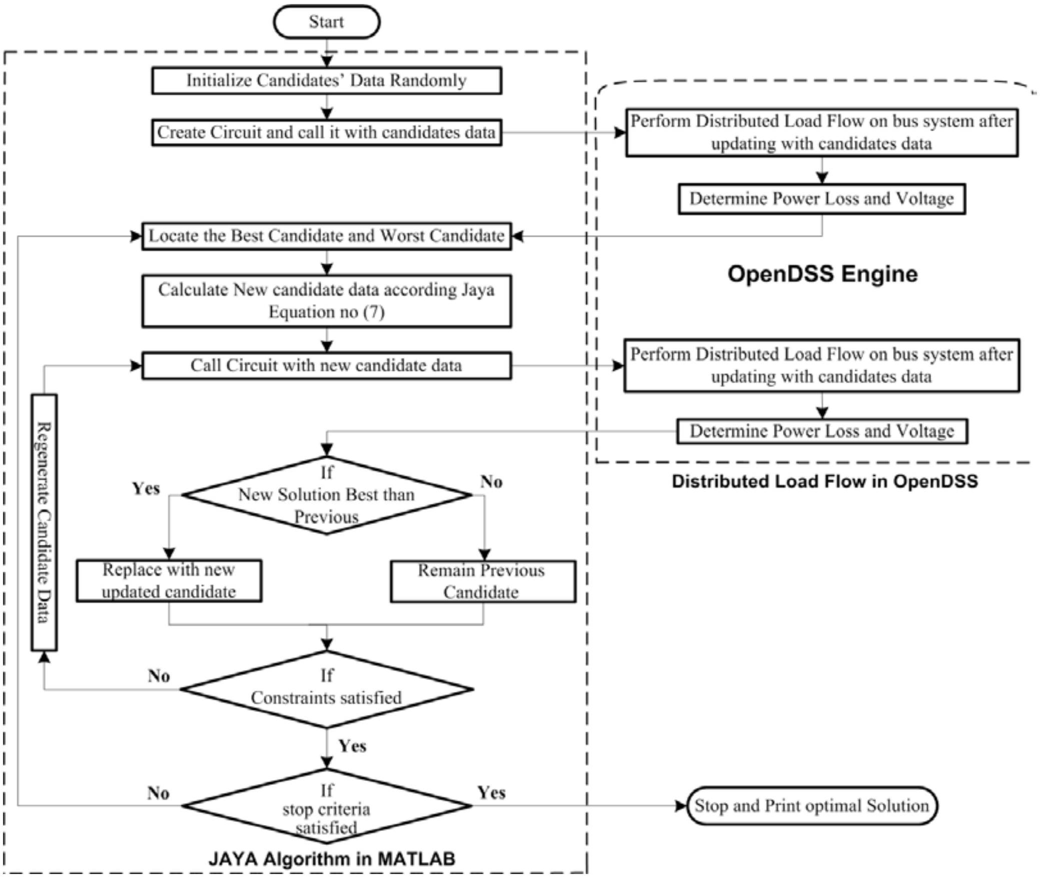

Fig. 2. Flowchart of the proposed approach

Step 1. Initialize common control parameters of the Jaya algorithm as number of candidates *m* (Population size), decision Parameters (S_z: DG Size, S_t: DG Site), number of design variables d_n and iteration itr (number of generations). Further specify the search criteria with lower and upper limits and define objective function.

Step 2. Randomly generate different size and site of the DGs for each candidate. Further run OpenDSS server engine and create circuit. Define DGs with candidate data and apply on the circuit via COM interface.

Step 3. Call circuit for distributed power load flow using the compile command and evaluate the objective function by calculating the power losses of the system as $Solution_{\alpha\beta}$ (where α =1, 2…*m* and ß = 1, 2….d_n).

Step 4. At the itr^{th} iteration, select a candidate who gets the best result and assigns it as $Best_\beta$ and detects the candidate who calculates the worst solution assigned as $Worst_\beta$. Further, apply the following equation on candidate's data:

$$Cand_{itr}^{new} = Cand_{itr}^{old} + r_1(\mathrm{Best}_\beta - \left|Cand_{\cdot itr}^{old}\right|) - r_2(\mathrm{Worst}_\beta - \left|Cand_{\cdot itr}^{old}\right|) \quad (7)$$

The above Jaya equation specifies the leaning of the solution to move closer to the best solution and the tendency of result to away from the worst solution.

Step 5. Further again call the circuit with newly upgraded candidates' data and determine the power losses in OpenDSS environment. If newly candidate data gives a better solution than previous data. Further, accept the new generated candidate otherwise remain as previously generated candidate's decision parameters.

Step 6. Moreover, apply the constraint handling mechanism to check the limits of the updated decision parameters, whenever it is not satisfied, then revise the generation process for S_z and S_t of the candidates. Further, ensure the updated DGs have not duplicate location. Moreover, it is repeated then to get rid-off from the duplicity.

Step 7. Terminate, if the maximum number of iterations is reached and achieved the optimal result. Otherwise, the accepted solutions from each iteration are maintained and these values are used as inputs for the next iteration. Further, run the whole process start from step 4 until stopping criteria is not satisfied.

4. Simulation Results

In this section, Jaya algorithm has been applied on Type I and Type III DGs which is tested on the IEEE 123-bus radial unbalanced distribution system [16] and compared with the results of well-established particle swarm optimization (PSO) [13]. Open source software openDSS has been used to solve the load-flow for the unbalanced radial distribution system. The Jaya algorithm has been implemented in MATLAB. Moreover, this approach is based on two-way data commutation between MATLAB and openDSS simulation engine. Four capacitor banks, four voltage regulators, overhead and underground distribution lines and three types of loads (constant current, constant impedance and constant power) are present in this test system. Therefore, this system considered all practical conditions for the realistic planning of the DGs.

In comparison of Jaya and PSO algorithm, seven most heavily loaded buses are chosen and find out the optimal sizes with respective nodes. The Jaya algorithm achieves the maximum power loss reduction at each node which is demonstrated in Table 1.

TABLE 1. COMPARISON OF THE OPTIMAL SIZE ACHIEVED FOR TYPE I DGS

Bus Number	**Load (kW)**	**PSO algorithm**		**Jaya algorithm**	
		Optimal Size	**Power loss reduction (%)**	**Optimal Size**	**Power loss reduction (%)**
76	245	2105	25	2196	66
48	210	1713	29	1641	34
65	140	1300	31	1233	38
49	140	1597	20	1598	33
47	105	1803	25	1712	35
64	75	1546	35	1505	44
66	75	1135	37	1130	38

DGs have got the optimal penetration after 100 autonomous trails. The percentage power reduction is maximized with the increase number of DGs with same penetration level. Further, applied algorithm obtained the more reduction of the power losses for each number of DGs. Table 2 show the optimal performance parameters and comparison of the system performance between the Jaya and PSO algorithm.

TABLE 2. COMPARISON OF SYSTEM PERFORMANCE FOR TYPE I DGS

DGs	PSO (DGs in MW)	JAYA (DGs in kW)	Power loss reduction (%)	
			PSO	Jaya
1	67(2.41)	67(2.36)	37.5	67.9
2	67(1.41), 72(1.57)	77(1.39), 35(1.25)	55.8	73.4
3	67(1.08), 72(1.32), 47(0.54)	64(0.58), 44(1.31), 86(1.11)	69.1	76.5
4	67(1.08), 72(1.32), 47(0.54), 114(0.25)	97(1.10), 76(0.76), 47(0.61), 35(0.53)	79.4	79.7

The Jaya algorithm achieved the better power loss reduction at each number of DGs as compare to the PSO algorithm for Type III DGs as present in Table 3. Type III DGs are operated with power factor of 0.87.

TABLE 3. OPTIMAL PERFORMANCE PARAMETER FOR TYPE III DGS

DGs	**PSO (DGs in MW)**	**JAYA (DGs in kW)**	**Power loss reduction (%)**	
			PSO	**Jaya**
1	60(2.4)	54(2.53)	23.4	56.9
2	60(1.49), 72(1.5)	39(0.52), 75(0.25)	34.7	69.7
3	60(1.19), 72(1.01), 58(0.82)	21(0.93), 160(1.52), 75(0.24)	47.1	74.7
4	60(1.06), 72(0.91), 97(0.52), 102(0.51)	67(1.03), 40(0.24), 40(1.25), 53(0.27)	62.5	79.6

Fig. 3 compares the bus voltage profile of phase A for Type I DGs in this test network. There is a substantial enhancement in node voltage profile which is obtained by the Jaya algorithm.

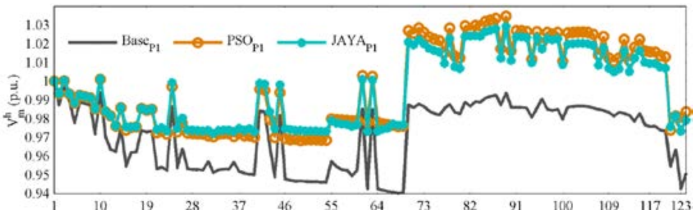

Fig. 3 Bus voltage profile of phase A for the IEEE 123 bus system

5. Conclusion

Integrating distributed energy resources in radial distribution system is striking the attention in the power system due to the more positive impacts. The Jaya algorithm has been executed in the structure of MATLAB by using the openDSS through component object model. This co-simulation framework obtained the optimum penetration of the Type I and Type III multiple distributed generators (DGs) at the particular places in the unbalanced distribution system. The applied method is compared with renowned particle swarm optimization algorithm. Further, Jaya algorithm achieved the maximum power loss reduction for each type and number of DGs in three-phase unbalanced IEEE 123 distribution system. Moreover, the voltage profile is also enhanced with the reduction of power of losses for each type of DGs.

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Biography

Prof. Ramesh Bansal has over 25 years of experience and currently he is a Professor and group head (Power) in the Department of EEC Engineering at University of Pretoria. He has published over 250 papers. Prof. Bansal is an Editor of IET-RPG & Electric Power Components and Systems. He is a Fellow and CEngg IET-UK, Fellow Engineers Australia and Institution of Engineers (India) and Senior Member-IEEE.