Hybrid Method for Optimal Placement of Multiple SPV Based Multiple RDGs in Microgrid System

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Abstract

A hybrid method has been suggested for optimal placement of multiple renewable distribution generations (RDGs) in microgrid system. The analytical approaches have not been appropriated for optimal placements of multiple solar photovoltaic (SPV) based on RDGs alone. In this work, hybridization of a fuzzy method and particle swarm optimization (PSO) search for the optimal placement of multiple RDGs in microgrid systems for decreasing the active power loss has been proposed. In this approach, the sizes of RDGs are evaluated at every bus by PSO method while the locations are determined by fuzzy based technique. The objective function (OBF) has been minimized under operating constraints. The improvements in nodal voltage profile have been observed. To confirm the proposed hybrid approach, results have been compared with bat algorithm (BA) technique and existing fast improved analytical (IA) method results. The suggested technique has been tested on 33-bus and 69-bus microgrid system.

1. Introduction

The common concerns about the environment, combined with the development of technologies to connect SPV sources to the grid and deregulation of electric power market have unfocused the attention of distribution system planners towards grid connected RDG. Optimization techniques have been employed for generation allocation in microgrid system, permitting for the best allocation of the RDG. There are many methods for deciding the optimal sizing and siting of RDG units in microgrid systems. Some of the factors that must be considered into account in the planning process of expanding distribution networks with RDG are the number and capacity of RDG units, best location, and technology, among others. Including RDG in microgrid systems requires in-depth analysis and planning tools. This process usually contains technical, economical and possibly environmental challenges [1-3].

Different methodologies have been developed to find optimal places to install RDG. These methods depend on analytical tools, optimization programs or artificial techniques. Most of them get the optimal allocation and size of one DG in to decrease losses and improve voltage profiles. Others contain the placement of multiple RDGs with artificial -based optimization techniques and a few go with analytical techniques. In [3], a genetic algorithm based method has been suggested to get the optimal placement of DG in the compensated distribution network for rebuilding the system caused by cold load pickup condition and to conserve load diversity for decreasing the power line losses. PSO algorithm has been used to calculate the optimal size and location of an RDG unit to reduce the active power losses with the site being discrete and the size being continuous. Singh D. has been minimized the active and reactive power losses in the networks, improvement in the voltage drop, and the distribution line loading with different load shapes[4]. In reference [5], an analytical technique has been modified to determine the optimum location–size pair of an RDG unit to reduce the line losses of the power system. Suchitra and et al. [6] have been stated that efficient and economical employment of RE networks in a hybrid system would necessitate the need for their optimal sizing.

Singh Rk. Moreover, et al. have been proposed a GA-based algorithm to determine the optimum size and location of multiple DG units to reduce the system losses and power fed by

the main grid, considering operational constraints into account [7]. In [8], an adaptive weight PSO algorithm has been planned to place multiple RDG units to reduce the active power loss of the system. A probabilistic-based planning technique has been proposed for determining the optimal fuel mix of different types of RDG units to minimize the annual energy losses in the distribution systems [9]. The analytical techniques may not be suitable for optimal placements of multiple RDGs alone. A hybrid approach has been proposed in the present work for optimal placement of multiple SPV based RDG. In this paper, hybridization of the fuzzy method and PSO search for the optimal placement of multiple RDGs in microgrid systems for reduction of power loss has been proposed. In this approach, the sizes of RDGs are evaluated at every bus by PSO technique while the locations are determined by fuzzy based technique. The objective function (OBF) has been minimized under operating constraints. The approaches tested on 33-bus and 69-bus test systems, and the gotten results are compared and also with obtained results of the analytical method.

2. Problem Formulation

The main goal of SPV based RDG allocation is to reduce the total active power losses of the microgrid with satisfying different constraints. The problem is to determine the optimal location and size of an RDG units in a known distribution system. For simplicity and without loss of generality, this optimization problem is formulated in this work with the aim of minimizing the real power losses. Other objectives such as the total cost of RDG units or the production costs are not considered here, but they could be included within the same methodology used. The losses in a system are dependent on the system operating conditions, and they are given by[10]:

$$P_{los} = \sum_{I=1}^{nbus} \sum_{J=1}^{nbus} [\alpha_{IJ}(p_I p_J + q_I q_J) + \beta_{IJ}(q_I p_J - p_I q_J)] \qquad (1)$$

In Equation (1) which is popularly known as 'exact loss' formula, subscripts I and J vary from 1 to the total No. of buses, nbus; p and q are net active and reactive power injection on each bus respectively; Eqs can calculate α_{ij} and β_{IJ}. (2 and 3).

$$\alpha_{IJ} = \frac{R_{IJ}}{V_I V_J} \cos(\sigma_I - \sigma_J) \qquad (2)$$

$$\beta_{IJ} = \frac{R_{IJ}}{V_I V_J} \sin(\sigma_I - \sigma_J) \qquad (3)$$

where, R_{IJ} is the active part of the impedance at row I and column J of the Z_{bus}, and V and σ are the voltage and load angle at related buses. However, in this work, a simplified loss formula has been used where the OBF P_{los} has been expressed as:

$$P_{los} = \sum_{I=1}^{nbus} \sum_{J=1}^{nbus} [R_{IJ}(p_I p_J + q_I q_J)] \qquad (4)$$

Equation (4) is obtained from Equation (1) Matching V = 1 and σ = 0 for all buses and they are equivalent when loss coefficients. α and β, are calculated in the case of an RDG penetration rate of 100% in the distribution system, that is when there is an RDG unit at each bus of sizing equal to the value of the load at that bus. Numerical results show that the accuracy gained by updating α and β is small and negligible, so these coefficients have been calculated in the above-mentioned case instead of in the base case.

2.1. The objective function

The problem of placement of multiple RDGs is to calculate the optimal sizes and locations of multiple RDGs to minimize the OBF as given in (5) while meeting the operational constraints. The OBF is to reduce the total active power loss as given in (4) while meeting the following constraints.

$$OBF = MIN(p_{los}) \tag{5}$$

2.2. Constraint
2.2.1. Power Balance Constraint

$$\sum_{n=1}^{nRDG} P_{SPV} + p_{sub} = p_{los} + p_d \tag{6}$$

where, p_d is the load demand, p_{sub} is the substation power generation, and P_{SPV} is the power output from SPV module.

2.2.2. Voltage Constraint
The voltage at each bus in the network should be within the acceptable range. American National Standards Institute (C84.1-1989) has specified that voltage variations in distribution systems should be controlled within the range of 13% to 10% lower and above the rated voltage respectively [11]. In this paper, the voltage variations are set at 0.9 pu and 1.1 pu, respectively.

$$V_{MIN} \leq V_M \leq V_{MAX} \tag{7}$$

where, V_M is the magnitude of the voltage at every bus, V_{MIN} and V_{MAX} are the minimum and maximum voltage respectively. The problem formulated above for the placement of multiple SPV have been solved by the Hybrid approach.
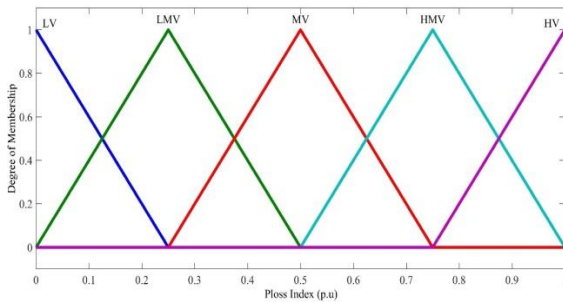

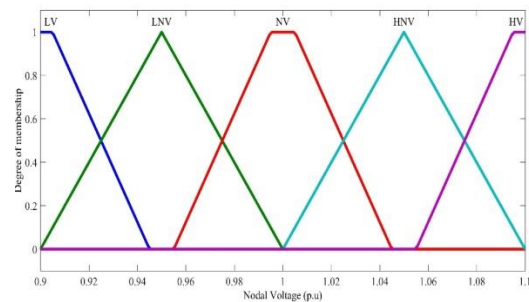Figure 1. Membership Function for PLI

Figure 2. Membership Function for Nodal Voltage

3. Hybrid Approach
In this work, OBF is considered while designing for making the optimal RDG sitting. The purpose of this work is to reduce the total active power losses, and the constraint is to keep the nodal voltage within the permitted limits. Bus voltages (V) and power loss index (PLI) of the microgrid system are representing by fuzzy membership functions. The fuzzy system consists of a set of rules is used to evaluate the RDG sitting suitability of every node in the microgrid system. RDG's can be set on the nodes with higher suitability value. First, the load flow program is necessary to get the total power losses. Second, load flow solution is needed to get the power loss sensitivity factors of the microgrid system. Third, the power losses sensitivity factors linearly regularized into a (0-1) range with the lowest power losses value is 0, and the largest power losses value is 1. The power Losses Index (PLI) value for nbus is calculated with the 25% of a load size of RDG put at every node. PLI can be expressed as:

$$PLI_{(M)} = \frac{(LOSSRED(M) - LOSSRED(min))}{(LOSSRED(max) - LOSSRED(min))} \tag{8}$$

where, PLI$_{(M)}$ is power loss reduction in (pu) at branch M, LOSSRED(M) is the loss reduction value at branch M, LOSSRED(max) is the maximum loss reduction, LOSSRED(min) is the minimum loss reduction. Inputs to FIS are two inputs PLI and V of buses. In this study, input 1 is PLI and Input 2 is V. The output is RDG Suitability Index (RDGSI). As show in the following Figures 1-3. The ranges of the input 1 (PLI) varies from zero to one, the input 2 (V) ranges from 0.9 to 1.1, and the output (RDGSI) ranges from zero to one. In the fuzzy inference system, five membership functions are selected for two input and the output as shown in the Figures 1-3. The membership functions for the PLI and RDGSI are triangular, but it is for the bus voltage are triangular and trapezoidal.
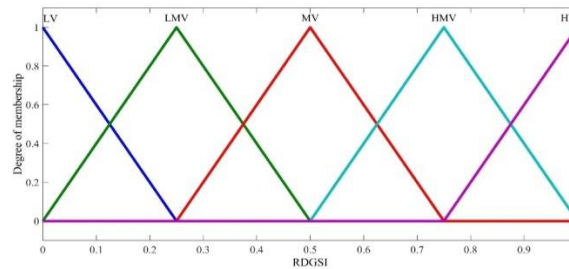

Figure 3. Membership Function for RDGSI

To get the RDGSI, a set of fuzzy rules has been established. The inputs to FIS are the V and PLI and the output is the RDGSI for best sitting. The rules are set in the fuzzy decision matrix shown in Table I. The optimal RDG sitting is known based on higher RDGSI.

Table 1. Fuzzy Decision Matrix

RDGSI		Nodal Voltage (V)				
		LV	LNV	NV	HNV	HV
PLI	LV	LMV	LMV	LV	LV	LV
	LMV	MV	LMV	LMV	LV	LV
	MV	HMV	MV	LMV	LV	LV
	HMV	HMV	HMV	MV	LMV	LV
	HV	HV	HMV	MV	LMV	LMV

4. Results and Discussion
4.1. The Test Systems
The performance of the proposed algorithm has been tested on IEEE33-bus[12] and IEEE 69-bus[13]have been taken as autonomous microgrid with different size, configurations and having different complexities. The first system has 33 nodes, and 32 branches as shown in Figure 4 and the total load demand is 3.72 MW and 2.3 MVAR. The MVA base and kV base of the 33-bus system are 100 MVA and 12.66 kV respectively. The second system is IEEE 69-bus with 69 nodes and 68 branches as shown in Figure 5 and the load demand is 3.8 MW and 2.6 MVAR. The MVA base and kV base of the 69 bus system are 100 MVA and 12.66 kV respectively.

4.2. Test System 1
The real power loss without placement of solar based RDGs is 210.1KW. Next, calculate the placement and sizing using the hybrid algorithm as shown in Table 2. From Table 2 it is clear that power loss is reduced effectively at highest penetration level. We can be noticed that the Average voltage from table 2 is increased from 0.9455to 0.981 with multiple SPV this is mean the voltage profile has been improved as shown in Figure 6. In Table 3, the proposed method is compared with BA technique. From Table 3 it is evident the hybrid algorithm performs well with reduced power loss Minimization. It is observed that voltage profile is improved effectively with a placement of SPV based RDGs. From the results, it is noticed that the proposed method minimizes the power loss effectively with satisfying all constraints.
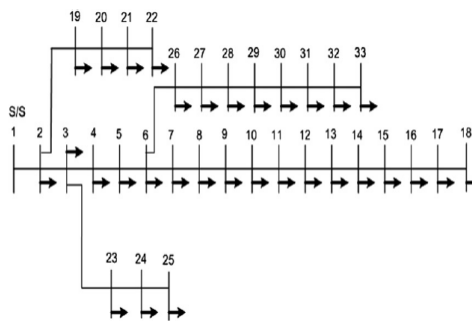
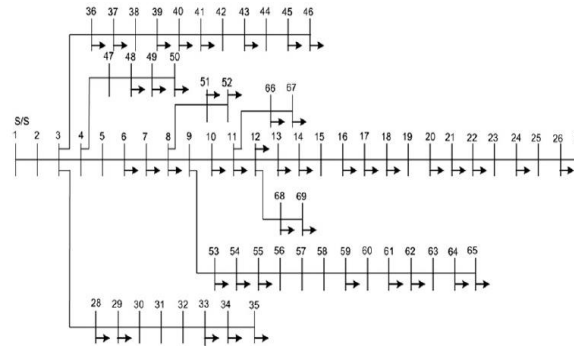Figure 4. A Single Line Diagram of 33-bus Microgrid
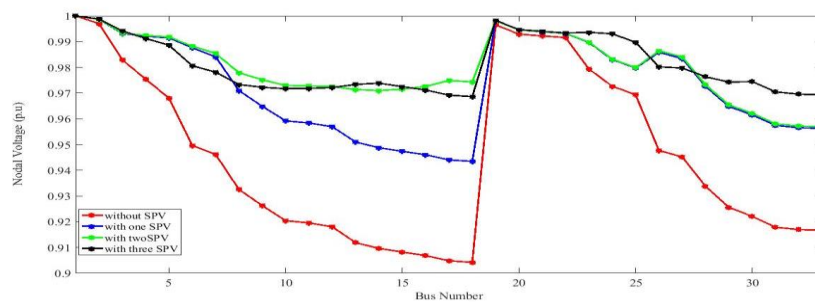
Figure 5. A Single Line Diagram of 69-bus Microgrid

Figure 6. Voltage Profile of 33-Bus without and with SPV based RDGs

Table 2. Optimal Allocation of SPV with Different RDG for 33-bus Microgrid

Test System	No of buses	Bus locations	Size of RDG (kW)	Losses (kW)	Reduction Power losses %	Average voltage (pu)
	1	6	2591.1	111.1	47.12	0.9730
33-bus	2	6	2128.7	93.5	55.49	0.9798
		17	475			
		30	1020			0.9810
	3	14	715.6	73.2	65.16	
		24	1040.7			

Table 3. Comparison of the Proposed Method with BA Methods

Technique	No of RDG	Location of RDG	Size of RDG (kW)	Power losses (kW)	% Reduction of Power losses
		15	816.3		
BA [14]	3	25	952.35	75.05	64.42
		30	952.35		
		30	1020	73.2	65.16
Hybrid System	3	14	715.6		
		24	1040.7		

4.3. Test System 2

The real power loss without placement of solar based RDGs is 225.1 kW. Next, calculate the placement and sizing using the hybrid algorithm as shown in Table 4. From Table 4 it is clear that power loss is reduced effectively at highest penetration level. We can be noticed that the Average voltage from Table 4 is increased from 0.9731 to 0.9936 with multiple SPV this is mean the voltage profile has been improved as shown in Figure 7. In Table 5, the proposed method is compared with IA technique. From Table 5 it is clear the hybrid algorithm performs well with reduced power loss Minimization. It is observed that voltage profile is improved

effectively with a placement of SPV based RDGs. From the results, it is noticed that the proposed method minimizes the power loss effectively with satisfying all constraints.

Table 4. Optimal Allocation of SPV Models with Different RDG for 69-bus Microgrid

Test System	No of buses	Bus locations	Size of RDG (kW)	Losses (kW)	Reduction Power losses %	Average voltage (pu)
69-bus	1	61	1874.5	83.2	63.03	0.9878
		61	1709.2	71.9	68.05	0.9926
	2	17	518.6			
		61	1709.2			
	3	17	423.9	69.7	69.04	0.9936
		10	400.9			

Table 5. Comparison of the Proposed Method with Analytical Approach Methods

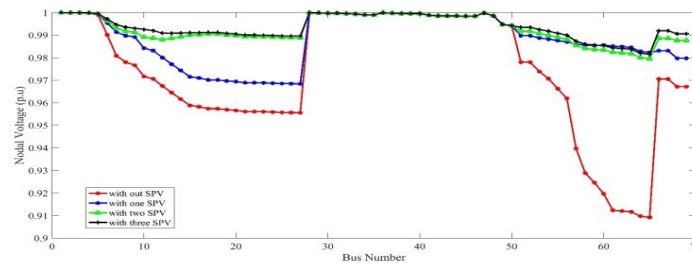| Technique	No of RDG	Location of RDG	Size of RDG (kW)	Power losses in kW	Base losses	% Reduction of Power losses
IA [15]	3	61	1700	70.24	225.27	68.82
		17	510			
		11	340			
Hybrid System	3	61	1709.2	69.7	225.1	69.04
		17	423.9			
		10	400.9			

Figure 7. Voltage profile of 69-bus without and with SPV based RDGs

5. Conclusion

In this work multiple SPV based RDGs are placed based on an approach to minimize the power distribution loss and the results obtained are compared. In the proposed hybrid approach, the sizes of RDGs are evaluated by PSO approach and the locations are determined by the fuzzy approach. The results obtained by hybrid technique have been verified using the bat algorithm (BA) and Improved Analytical (IA) The proposed hybrid approach for optimal placement of multiple types of RDGs not only reduces the line losses but also improved the average voltage profile of RDGs with the satisfaction of the permissible voltage limits. The number of RDG units with appropriate sizes at optimal locations can reduce the losses to a considerable amount. The results clearly indicate that hybrid method minimizes the power losses effectively in the 33-bus and 69-bus microgrid.

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