RELIABILITY STUDY OF A MICRO GRID SYSTEM WITH OPTIMAL SIZING AND PLACEMENT OF DER

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ABSTRACT

Microgrids comprise a network of small scale distributed energy resources (DERs) like fuel cells, micro turbines, PV arrays and wind turbine etc. and energy storage devices. Current deregulation regime is encouraging open competition amongst the small/medium utility service providers in providing quality and reliable 'clean' power to the customers at an economic rate. Economic power production is related to higher operational efficiency of the generating and distribution systems. In the reforming process, taxes and penalties imposed on the tariff system, like environmental pollution tax, contracted failure penalties etc. are posing problems for the fossil fuel plants. Microgrids with environment-friendly DERs have an edge over such problems. Microgrids also reduce line loss and CO2/NOx emission, increase overall energy efficiency through CHP operation, relieve T&D congestion and defer investments to upgrade existing generation. However, all these benefits could be achieved if DERs of the Microgrids have optimal size and location. This paper presents Particle Swarm Optimization (PSO) technique to determine optimal size and location of the DER in a meshed network for maximizing the economic benefits by minimizing the line loss.

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INTRODUCTION

With the advent of deregulation and restructuring regime, steep competition has already been unleashed among the utility service providers in macro-grid level. Though in the nascent stage of implementation, micro-grid system could not be spared of such competition in future[1,2]. Power market has turned its face from monopolistic set-up, i.e., centralized government control, to oligopolistic where several utility providers, called IPP, compete to win a share of market and bid against each other to supply electricity to consumers.[4] Many countries have already adopted, or, are thinking of adopting power pool concept, where, like stock exchange, both utility providers and consumers can participate for choosing each other through double sided bidding. All these developments in the power sectors are ushering a new hope of making electricity available at the doorstep of consumers with reliability and economy.[6] Economically reliable system is possible if utilities could adopt latest technology to improve the overall efficiency of their system from fuel stage to power delivery stage. With the continuous developing technology, highly efficient DERs are now available in the market. .

The effect of adding DER on network security and reliability will vary depending on its type and position of the DER at the connecting buses.[7,8] Both reliability and economic issues should be assessed subject to the DER capacity, mode of operation (i.e., whether running for economical reason or emergency), local grid stability and reliability criteria. This paper investigates how line losses are related with the size and location of DER. Simulation results show that optimal size and location of the DER would reduce losses normally seen by the system, while improper placement may, actually, increase it. The optimization is carried out using particle swarm optimization (PSO) algorithms and the results are compared with the results obtained by fast evolutionary programming (EP) technique. PSO is one of the evolutionary computation techniques.[5] It was developed through simulation of a simplified social system and has been found to be robust in solving continuous, non-linear as well as discrete optimization problems. The PSO technique can generate high quality solution within shorter calculation time and has more stable convergence characteristics than other stochastic methods. Whereas EP is a technique to search for the optimal solution to a problem by evolving a population candidate solution over a number of generations or iterations.[9] The solution is evolved through mutation and competitive selection.

MATHEMATICAL FORMULATION

For the line loss (P_{loss}) minimization, objective function is given by

$$MinP_{loss} = \sum_{i=1}^{n} P_i \quad (1)$$

where, P_i = Active Power injection at i-th Bus
= Active Power Generation (P_{Gi}) at the i-th Bus
– Active Power Demand at i-th Bus
n = Total no. of Buses.

Subject to reliabilities constraints

i) Bus voltage tolerance limit

$$V_{i\,\min} \le V_i \le V_{i\,\max}$$

ii) Limit on the active and reactive power generation of the DER

$$P_{i\,\min} \le P_i \le P_{i\,\max}$$

$$Q_{i\,\min} \le Q_i \le Q_{i\,\max}$$

iii) Line flow limits (e.g. they must be below thermal limits)

$$S_{ij} \le S_{ij\,\max}$$

$$\min P_{loss} = P_1(|V|, \delta) + \sum_{i=2}^{n} P_i$$

Where, P_1 (Slack Bus Power Injection) is dependent on other Bus voltage magnitudes $|V|$ and angles δ; and therefore it can be obtained by existing power flow solution.

SYSTEM DESCRIPTION

A six bus meshed network, as shown in fig. 1, has been considered for the case study. Among the six buses, bus no. 1 is slack bus. Slack bus, here, is the macro-grid. This paper uses macro-grid as a large virtual generator, which supplies the micro grid system whenever there is a shortfall of local generation. This happens when there is outage of DERs.The system peak demand is assumed as 1.85 p.u. and its distribution is shown as per bus data table II**.** It presupposes that one DER of capacity 1.2 p.u. is, already, connected to bus no. 2 of the system.

Purpose of the paper is to find out methodology of selecting proper size of the second DER and its suitable location among the four PQ- buses, so that line loss is reduced to a minimum. This is a constrained discrete optimum searching problem and PSO algorithms are used for its solution and the results obtained by PSO have been compared with the corresponding results of EP. Table 1 gives the line data of the system.

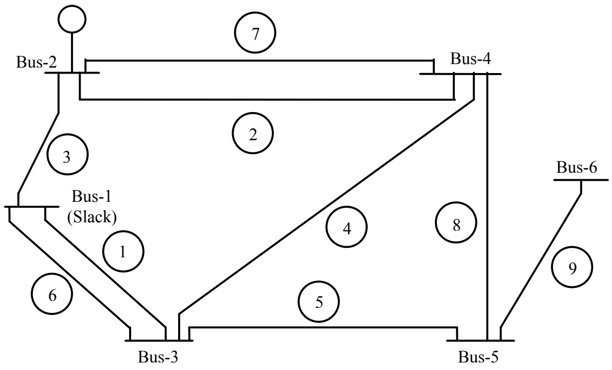

Fig. 1: Six Bus Meshed Network

Table-I: Line Data (values are in p.u.)

Line No.	R	X	B
1	0.0342	0.18	0.0106
2	0.114	0.60	0.0352
3	0.0912	0.48	0.0282
4	0.0228	0.12	0.0071
5	0.0228	0.12	0.0071
6	0.0342	0.18	0.0106
7	0.114	0.60	0.0352
8	0.0228	0.12	0.0071
9	0.228	0.12	0.0071

Table-II: Bus Data (values are in p.u)

Bus No.	Real power generation	Reactive power generation	Real load demand	Reactive load demand	Voltage specification
1	0.0	0.0	0.0	0.0	1.05+j*0
2	-	0.0	0.2	0.065	-
3	-	0.0	0.85	0.279	-
4	-	0.0	0.4	0.1312	-
5	-	0.0	0.2	0.065	-
6	-	0.0	0.2	0.065	-

SIMULATION TECHNIQUE

For comparison of results, two soft-computing techniques- PSO and EP do simulations, separately.

PSO technique conducts search using a population of particles corresponding to individual as a potential solution to a problem, having N-dimensional space with a memory of its previous best position as well as the best position among all particles in addition to a velocity component. At each iteration, the particles adjust their velocity along each dimension, which, in turn, gives the new particle position. Updating of each dimension is independent.

In this study authors have assumed following PSO data;

a) Population size: 20;
b) Acceleration Constants: C_1,C_2 = 2;
c) Generation or iteration = 1000;

d) Inertia weight factor: w_{max}=0.95 and w_{min}=0.2.
e) Constriction Factor = 1.0;

EP searches the solution to a problem by evolving a population of candidate solutions over a number of generations or iterations. The mutation in EP generates new offspring from the current population and this proves to be more efficient in terms of speed. As for a fast EP technique, authors use both Gaussian and Cauchy mutations, together, for creation of offspring from the same parents and better ones are chosen for the next generation.

EP data used in the case study are as follows:
Population Size=20;
Scaling factor = β =0.05;
Iteration No.=1000;

CASE STUDY

It is clearly seen that DER can reduce the line loss in the system. This is due to the fact that DER supplies a portion of real and reactive power to the load. Thus, the line current reduces in the region from the source to the location where DER is installed and it results in lower electrical line loss. But, higher DER ratings can't always guarantee lower line loss. Hence, selection of proper location and size of DER is well justified. This fact should be taken into account before determining the size and placement of DER. The suitable rating, mainly, depends on the amount and location of the load in the bus. Generally, higher the amount of load, the penetration of DER can be higher without causing higher electrical loss. In this paper, authors have selected maximum line flow, bus voltages, slack bus injection and system line loss as the parameters to judge the reliability condition of the system. Reduction of slack bus power injection can mitigate the utility's line congestion, whereas maximum line flow is the indicator of internal congestion. The range of DER capacity in the study has been kept within limit 0.6 p.u. to 0.8 p.u. to lower the slack bus power injection. Table IIIA and Table IIIB show the results of optimal size and location of DER using both PSO and EP, separately, at four PQ-buses after 1000 iterations and 50 trials. Table IV shows the comparison between the two methods used in accordance with their time of searching as well as reaching at the minimum value of the objective function. Average time for completion of 1000 iterations in both the cases differs slightly, but final minimum value of PSO is better than that of EP.

Table – IIIA

Optimal results in PSO and EP after 1000 Iterations and 50 Trials (all values are in p.u)

DER at PQ-Bus No.	Optimal Size of DER		System Loss (Lowest Minimum Value)		Slack Bus Injection (P_1)		Maximum Line Flow (S_{ij})	
	PSO	EP	PSO	EP	PSO	EP	PSO	EP
3	0.6006	0.6000	0.0720	0.0770	0.1213	0.1270	0.3170	0.3161
4	0.6002	0.6000	0.0966	0.1083	0.1464	0.1583	0.4124	0.4093
5	0.7806	0.6000	0.0828	0.1067	-0.0478	0.1567	0.3687	0.3380
6	0.7056	0.6000	0.1133	0.1240	0.0577	0.1740	0.5738	0.4591

Table – IIIB
Results of PSO after 1000 Iterations and 50 Trials (all values are in p.u)

Find DER at Bus No.	Optimal Size of DER	P_{loss} (Best min. value from 50 Trials)	Voltage at BUS (p.u.)					
			1	2	3	4	5	6
3	0.6	0.0778	1.0	1.0	1.0	0.9787	0.9769	0.9642
4	0.6	0.1060	1.0	1.0	0.9764	1.0	0.9755	0.9628
5	0.7953	0.0871	1.0	1.0	0.9778	0.9796	1.0	0.9877
6	0.6040	0.1270	1.0	1.0	0.9629	0.9605	0.9702	1.0

Table-IV
Comparison between PSO and EP

	System Loss (p.u)			Computation Time per 1000 Iterations (Sec.)		
	Max.	Min.	Average	Max.	Min.	Average
EP	0.0829	0.0797	0.0820	58.00	51.58	56.7420
PSO	0.0758	0.0720	0.0728	69.31	48.61	56.5842

COMPUTER ALGORITHMS

Gauss-Siedel load flow method has been used with each of PSO and EP algorithms for finding out the optimal solution. The computational steps are as follows:

1. Initialize the DER position at PQ-bus no.3 (i.e., index= 3). Type of Bus no.3 is, then, changed from PQ to PV.
2. Read the input data:- Bus data (from Table I), Line data (from Table II**)**, no. of buses (nb), no. of lines (nl) etc.

3. Run the program to obtain line losses for each of the 20 populations (in our case DER size) using PSO, or, EP techniques.
4. Run step 3 for 1000 iterations and then for 50 trials. Find out the lowest of 50 minimum line losses.
5. Shift the DER to other PQ-buses (i.e., 4, 5, and 6) step by step and in each step index is incremented by one
6. Repeat steps 3 and 4, as long as index<=nb
7. Compare the lowest vales of four PQ-buses and select the best one. Corresponding bus position and size of the DER would be the desired optimal value.

ANALYSIS OF RESULTS

After simulating at all the four PQ-bus locations using PSO and EP, separately, results obtained are shown in Table III. It is important to note that best location of DER is achieved at the PQ-bus no.3 where system line losses of value 0.072 p.u.is found lowest among the four buses and the corresponding optimal size of DER is coming out 0.6006 p.u.as per PSO. Results from EP are tallying very nearly with the PSO. In contrast, the worst location occurs at bus no. 6 where line loss is at maximum of 0.1133 p.u. as per PSO and corresponding DER size is found as 0.7056 p.u. Whereas corresponding results from EP are 0.1240 p.u. and 0.6 p.u. respectively. With the second DER at bus no. 3, slack bus injection, maximum line flows are found lowest. As load at bus 3 is highest of all buses, final best minimum value loss value occurs with high DER penetration at bus 3. Fig2 depicts how each of PSO and EP searches final best solution. Final best value attained by PSO is 0.072 whereas by EP is 0.077. These values correspond to second DER at bus 3.

CONCLUSION

Authors have assessed the reliability of the micro-grid on the basis of comparison of following parameters- lowest line loss, lowest congestion, and within-limit bus voltage values. Use of micro-grid system is one of the many strategies electric utilities are considering operating their system in the de-regulated environment. This paper has presented a methodology to find optimal capacity and placement of DER in respect to a security constrained six bus meshed distribution micro-grid. A systematic and rational placement of DER improves both system security and reliability, by improving voltage profile of buses and reducing losses as well as congestion. The level of improvement depends on the type, number, size, and placement of DERs. PSO and EP techniques have been used, here, successfully to assess the reliability of the present micro-grid system. The results, clearly, indicate that the inclusion of DER in the micro-grid does not, always, guarantee the minimization of line loss. The benefits obtained by the introduction of DER should be weighed against the costs involved, before deciding on the use of DER. With the more and more improvement in DER technology, Cost is coming down and their use is expected to rise. Value-based reliability assessment is to be done, as future work, to get a clear picture of the assessment.

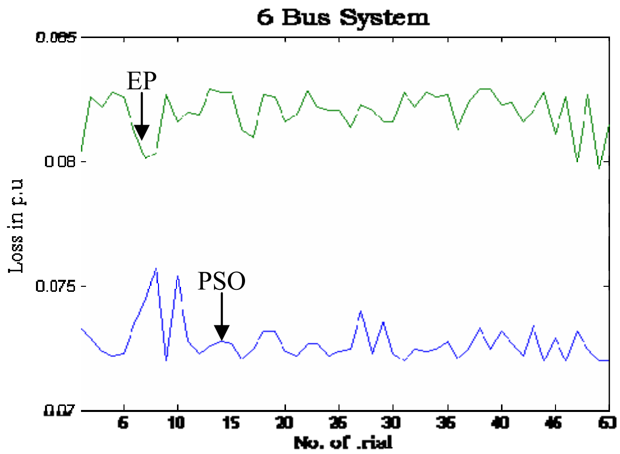

Fig. 2 Final Best Solution

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