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Research paper



Multi-Objective Approach for Optimal DGPV Location and Sizing

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Abstract

The advancement of renewable technology has attracted utility and company to integrate and produce energy for a cleaner environment. The attractive policy from the government also gave the opportunity to adopt the technology recently. The Distributed Generation Photovoltaic (DGPV) integration into the grid is an advanced technology to produce electricity without polluting the environment. Besides providing the green technology, it can also enhance the voltage profile and minimise the transmission losses. However, this depends on the location and the sizing of the DGPV. In this paper, the location and sizing of DGPV are deduced using multi-objective Chaotic Mutation Immune Evolutionary Technique (MOCMIEP) technique. The proposed method determines the optimal location and sizing of DGPV and to improve the losses and *FVSI* simultaneously. *FVSI* is a pre-developed voltage stability index based on the line in the power system. The method was tested on the power transmission system of IEEE 30-Bus and IEEE 57 -Bus Reliability Test System (RTS). The results demonstrate the ability of the proposed method to generate the Pareto optimal solutions of the multi-objective problems and come out with the best compromise solution.

Keywords: *Multi-objective; Pareto optimal solutions; voltage stability; DGPV placement.*

1. Introduction

Nowadays, the increasing energy consumption and the limitation of new transmission lines have created the interest in integrating distributed generation photovoltaic (DGPV) into the power system. In addition, many researchers have proved that by having DGPV in the system, the voltage profile will be improved and power losses can be reduced [1]. In order to gain the benefits, optimal location and size of DGPV are considered as crucial issues for both utility and DGPV owners [2].

In real-world problems, the optimisation often deals with several contradicting objectives at the same time. Therefore, the multi-objective optimisation is essential as the single objective optimisation experienced limited solution. Finding the optimal location and sizing of DGPV in the transmission system also falls in multi-objective optimisation since there is a trade-off between the voltage stability index and the active power loss. Artificial Bee Colony (ABC) has been used in [3] in finding optimal location and sizing of DGs in distribution radial network. This work can be considered as multi-objective optimisation (MOO) approach since the primary objectives are to minimise the line losses and to minimise the operational cost of DG placement by using the weighted sum approach. This research proved that with appropriate location and sizing of DG the utility could save the operational cost up to 33%. On the other hand, B. Poornazaryan in [4] proposed a new index for optimal location of DG in the radial distribution network. In this study, a modified form of Imperialistic Competitive Algorithm (ICA) method was used to solve the problem by minimising the power losses and the voltage stability margin simultaneously. The research has concluded that installing DG units in distribution systems is an effective measure to minimise losses. A new multi-objective performance index (MOPI) for evaluating the optimal DG location and size is applied in [5] by using the weighting method in which the weighting factors are chosen heuristically to combine multiple objectives into one objective function. Difficulties in finding the appropriate weighted factor that leads to the imprecise solution [6] have been identified as the drawbacks. Another work in [7] enhances the hybrid Particle Swarm Optimisation (PSO) for dealing with MOO problems. Moreover, fuzzy logic strategy to select the best compromise solution on the Pareto front has been embedded in this study. The objectives that are considered in this work are minimising both power loss and voltage stability index.

This paper presents the application of MOCMIEP to the DGPV placement and sizing problem having two objectives which are voltage stability index and power losses. The MOCMIEP algorithm is developed to find the Pareto optimal solutions to the problem. The proposed algorithm is demonstrated to solve the problem for three DGPV units in two systems which are the IEEE 30-Bus RTS and IEEE 57-Bus RTS. Results obtained from the study can be beneficial to power system community in planning their system in future.

2. Research Method

The proposed MOCMIEP is applied to two IEEE test systems which are the 30-Bus RTS and 57-Bus RTS. The cases, which are evaluated, are summarised in Figure 1. The experiments are implemented in MATLAB® R2016b. The experiment is simulated for 20 runs and the best compromise solution is then recorded.

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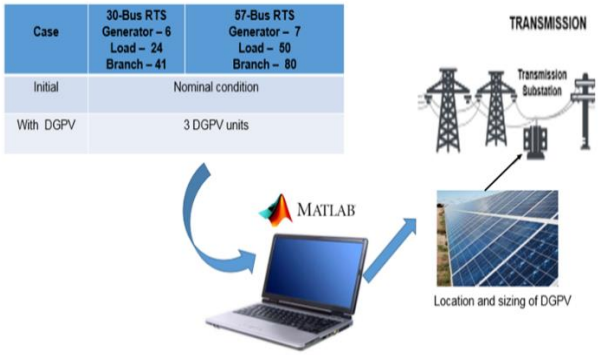


Fig. 1: Summary of cases for the experiments.

2.1. Multi-Objective Optimisation

The multi-objective optimisation problem is a real-world optimisation problem that deals with the optimisation of several conflicting objectives. Generally, two conflicting objectives are impossible to minimise or maximise at the same time. Mathematical relationship to generally describe multi-objective functions is shown in Equation (1)[8]:

$$\text{minimise } F(x_i) = \{f_1(x_i), f_2(x_i), ..., f_i(x_i)\} \quad (1)$$
$$\text{for } \forall x \in m \wedge \forall i \in M$$

$$subject\ to: \begin{cases} g(x) = \{g_1(x), g_2(x), ..., g_3(x)\} \\ h(x) = \{h_1(x), h_2(x), ..., h_3(x)\} \end{cases}$$

Where $F(x)$, $f_1(xi)$ and $f_2(xi)$ are combined, 1st and 2nd objective function respectively. *m* and *M* are the vector control of the variables and the number of individuals in the population respectively. $g(x)$ and $h(x)$ are inequality and equality constraints respectively.

2.2. Objective Functions

In this paper, two objective functions are considered to be minimised simultaneously. The first objective is to minimise the highest voltage stability index value developed by I. Musirin in [9] as characterised in Equation (2):

$$f_1 = min(FVSI_{max}) = min\left(max\left(\frac{4Z^2Q_j}{V_i^2 X}\right)\right) \quad (1)$$

where
Z is line impedance
X is line reactance
Q is reactive power at the receiving end
V_i is voltage at the sending end

The second component of the objective function represents the total active power losses in the system, P_{loss}. The losses can be expressed by Equation (2):

$$f_2 = min(P_{loss,i}) for\ \forall i \in nr \quad (2)$$

where
nr is the number of transmission lines.

The DGPV location and sizing are based on minimisation of the two objective functions, *FVSI* and active losses simultaneously, while satisfying all equality and inequality constraints. This problem is formulated as a multi-objective optimisation problem with non-linear constrained as shown in Equation (3):

$$Min\ \ F = [f_1, f_2] \quad (3)$$

2.3. Inequality Constraints

All the objective functions are subjected to the following inequality constraints:

2.3.1. Generating Capacity

The generating capacity is defined as follows:

$$P_{DG,i}^{min} \le P_{DG,i} \le P_{DG,i}^{max} \quad \forall i \in N \quad (4)$$

Where $P_{DG,i}^{min}$ and $P_{DG,i}^{max}$ are the minimum and the maximum output of DGPV respectively and *i* is the total bus number.

2.3.2. Bus Voltage

The bus voltage constraint is defined as follows:

$$v_{min} \le v_i \le v_{max} \quad \forall i \in N \quad (5)$$

Where V_{min} and V_{max} are the lower and the upper bound of bus voltage limit respectively and V_i is the voltage magnitude at bus *i* for all the *N* bus.

2.3.3. Power Balance

The power balance constraint is shown in Equation (6):

$$(P_{G,i} - P_{D,i} + P_{DG,i}) = P_{loss} \forall \in N \quad (6)$$

Where $P_{G,i}$, $P_{D,i}$, $P_{DG,i}$ and P_{loss} are the active power of bus generator, active load and active power losses respectively. *i* is the total bus number.

2.3.4. Voltage Stability

The stability constraint to ensure the system remains in a stable condition with the presence of DGPV is as follows:

$$0 < FVSI \le 0.95 \quad (7)$$

3. Pareto Optimal Solutions

The Pareto optimal or non-dominated solution is a set of solutions also known as a set of good compromise solutions. Other solutions do not dominate any individual in this set. In domination concept for minimisation of two objective functions, a solution x_1 dominates solution x_2 if x_1 is not worse than x_2 in all objectives and x_1 is better than x_2 in at least one objective [9]. Therefore, x_1 is known as a non-dominated solution. The mathematical of this expression is shown in Equation (8).

$$x_1\ \phi\ x_2\ if \quad (8)$$
$$\forall i\ :\ f_i(x_1) \le f_i(x_2) \wedge \exists\ j\ :\ f_j(x_1) < f_j(x_2)$$

Where $j=1,2,...O$ and O is the number of the objective function.

A set of solutions that are non-dominated in the entire search space is known as Pareto optimal solution or optimal front. The

concept of non-dominated solutions and Pareto optimal front is shown in Figure 2.

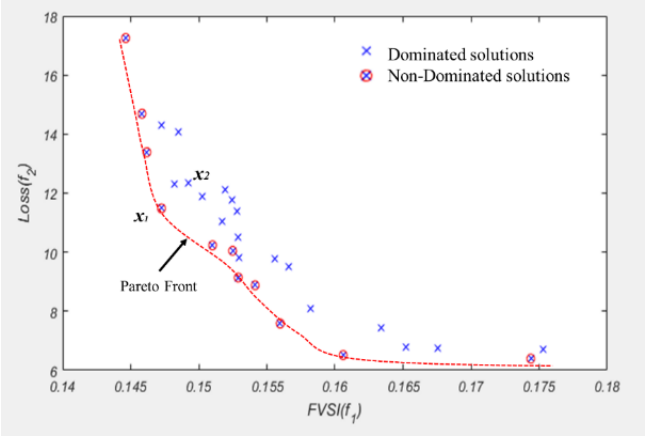


Fig. 2: Pareto optimal front for multi-objective optimisation

4. Multi-Objective Chaotic Mutation Immune Evolutionary Programming (MOCMIEP)

The multi-objective optimisation is a suitable engine to deal with different conflicting objectives to get the best solution. In this paper, the CMIEP developed in [10] is used to perform the multi-objective optimisation for the location and sizing of the DGPV. The steps of MOCMIEP that are established to achieve a set of best trade-off among the two objectives in the DGPV location and sizing are described in the following steps:

Step1: Initialisation of the iteration, $i=1$ and randomly generate P_i of the initial population known as a parent.

Step 2: Cloning of the parent, P_i to create $10P_i$ number solution in the present population.

Step 3: Mutation to produce the offspring population, P_f.

Step 4: Combination of parent and offspring population to create a total population, P_t.

Step 5: Identification of the non-dominated solutions and rank the solutions based on the fitness value by counting the number of solutions that dominate the other solution in the current population.

Step 6: Sorting the solution in the ascending order based on the fitness value assigned in Step 5.

Step 7: Select the first solutions as the parent for the next iteration

Step 8: Abort the algorithm if the maximum number iteration is met and present the Pareto optimal front. Otherwise, go to Step 2.

5. Implementation of MOCMIEP to DGPV Sizing and Location

The implementation of MOCMIEP in solving the DGPV sizing and location is presented in the following steps:

Step 1: Initialisation: the initial population known as parent individuals, N_p comprises of the location and sizing of the DGPV which satisfy all the constraints. The locations of the DGPV ranging over $[1, N]$, where N is a total number of load bus in the system. The range of DGPV size is shown in Equation (5).

Step 2: Cloning: The parent individuals are subjected to the clone multiplier to produce more parent individuals, $2N_p$.

Step 3: Mutation: Chaotic mutation is performed on each parent individual by adding chaotic mapping random number. Mutation results create the offspring individuals, N_o. The general formula based on chaotic mutation technique is given in Equation (9):

Where

$x_{i+m,j}$ and $x_{i,j}$ = offspring and parent

β = mutation scale

$x_{j,max}$ and $x_{j,min}$ = minimum and the maximum value of the parent

f_i and f_{max} = individual fitness and maximum fitness

C = Piecewise linear chaotic mapping variables

Step 4: Combination: The combination of parent and offspring population to produce N_T. Then, the individuals in N_T population are evaluated by two fitness functions, f_1 and f_2 separately.

Step 5: Non-dominated ranking: The ranking process of finding a non-dominated solution in the current population, N_T using individual's fitness f_1 and f_2. The ranking was assigned to each solution that dominates the other solution.

Step 6: Selection: The solutions are sorted out in the ascending order concerning the rank assign to each solution. The first N_p solution will be selected as parents for the next generation.

Step 2 to last are repeated until the maximum number of iterations is met, then the Pareto optimal front is presented.

6. Best Compromise Solution (BCS)

Pareto optimal front is a set of several compromise solutions. The decision maker's responsibility is to define the best solution by the experiences and intuitive knowledge among these solutions. On the other hand, a decision can also be made by using the formulation of best compromise index [11], as shown in Equation (10) to choose only one best solution.

$$\alpha = \frac{\sum_{k=1}^{M} u_i^k}{\sum_{i=1}^{N_{obj}} \sum_{k=1}^{M} u_i^k} \tag{10}$$

The variation of u_i^k is determined by the following equotions.

$$u_i^k = 1 \quad if \quad \left(F_i^k > F_{max}^k\right) \tag{11}$$

$$u_i^k = \frac{F_{max}^k - F_i^k}{F_{max}^k - F_{min}^k} \quad if \quad \left(F_{min}^k \le F_i^k \le F_{max}^k\right) \tag{12}$$

$$u_i^k = 0 \quad if \quad \left(F_i^k < F_{min}^k\right) \tag{13}$$

7. Results and Analysis

The IEEE 30-Bus and IEEE 57-Bus RTS have been selected as the case study in this paper. The solutions were obtained for the placement of three units of DGPV in the system for minimization of *FVSI* and active power loss with respect to the constraints. The assumptions for the algorithm's parameters are shown in Table 1. In this case, three DGPV have been installed considering their active power generations constraints as $10MW \le P_{DG,i} \le 60MW$. These units can be installed only in load buses of the system.

Table 1: Parameters for Simulation

Population	= 200
β	= 0.001
Generation	= 1000

$$x_{i+m,j} = x_{i,j} + C\left(\beta\left(x_{j,max} - x_{j,min}\right)\frac{f_i}{f_{max}}\right) \tag{9}$$

7.1. Simulation Results on IEEE 30-Bus RTS

Table 2 showed the best solutions for DGPV placement and sizing for IEEE 30-bus RTS out of 20 runs. From the table, the three optimal locations are bus 24, 7 and 18 with the sizing of 51.57, 52.75 and 40.06 MW respectively. All of these DGPVs are installed at the PQ bus. Table 3 highlighted the comparison of *FVSI* and power losses of the system before and after the installation of three DGPV units into the system. It can be seen that with the installation of DGPV, the *FVSI* has been reduced by 27% from 0.2035 to 0.1478. Simultaneously, the percentage of loss reduction is 65.9% i.e. from 17.0 MW to 6.00MW. These results imply that with the DGPVs installation at optimal locations with optimal sizing can help in the reduction of power losses and *FVSI* in the system.

Table 2: Location and sizing of DGPV units in IEEE 30-bus system

DGPV		
Unit	Location (Bus)	Active power generation (MW)
1	24	51.57
2	7	52.75
3	18	40.06

Table 3: The performance of objective functions before and after the DGPVs installation

	Without DG	With DG
System *FVSI*	0.2035	0.1478
System power loss (MW)	17.60	6.00
Total power of DGPV units (MW)	-	144.38

Figure 3 shows the non-dominated solutions known as the Pareto optimal front for the trade-off between the power losses and the *FVSI*. The BCS is achieved by applying the formula in Equation (10).

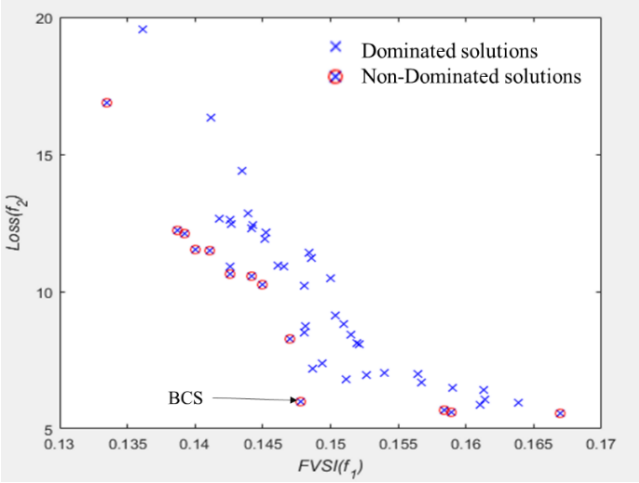


Fig. 3: The trade-off between power losses and *FVSI* for 30-Bus RTS

7.2. Simulation Results on IEEE 57- Bus RTS

The proposed method is applied to IEEE 57-bus RTS and a similar trend has been observed. Table 4 presented the solutions for this case study. Based on the results, the optimal locations of DGPV are at buses 18, 51 and 49. The sizes of the DGPV units are 35.48 MW, 49.29 MW and 59.75 MW respectively. Moreover, the improvement of power losses and *FVSI* after the installation is shown in Table 5. As can be seen, the power losses are reduced by the amount of 11.32 MW from 27.85 MW to 16.53 MW. Simultaneously, the *FVSI* is reduced from 0.4058 to 0.3909, which indicates an improvement in the system stability condition.

Table 4: Location and sizing of DGPV units in IEEE 57-bus system

DGPV		
Unit	Location (Bus)	Active power generation (MW) generation (MW)
1	18	35.48
2	51	49.29
3	49	59.75

Table 5: The performance of objective functions before and after the DGPVs installation

	Without DG	With DG
System *FVSI*	0.4058	0.3909
System power loss (MW)	27.85	16.53
Total power of DGPV units (MW)	-	144.52

Figure 4 shows the trade-off between two objective functions for IEEE 57 bus system. In this case, a set of Pareto optimal fronts is deduced and the best compromise solution is found by using the formula in Equation (10).

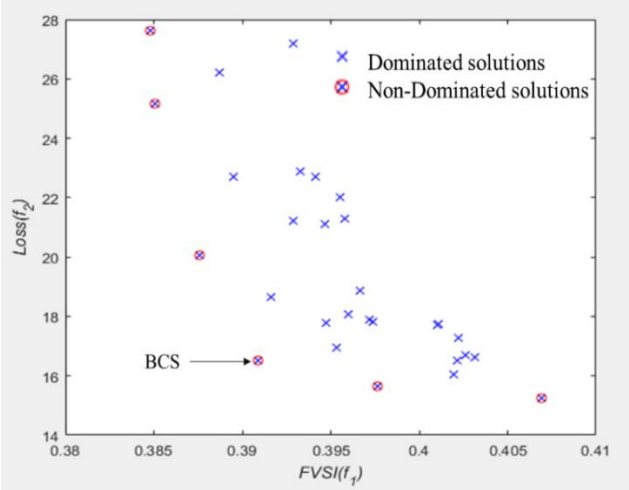


Fig. 4: The trade-off between power losses and *FVSI* for 57-Bus RTS

4. Conclusion

A multi-objective DGPV allocation algorithm known as MOCMIEP has been developed to ensure the system power losses and voltage stability index will be minimised with respect to several constraints. The algorithm has been applied to IEEE 30 bus system and IEEE 57 bus system for allocation of three DGPV units. From the results, it can be concluded that by optimally allocating the DGPV units with optimal size, the system power losses can be decreased and voltage stability index can improve simultaneously. These results are based on the best compromise solution of the trade-off of two conflicting objective functions. Results also showed that MOCMIEP method is suitable for obtaining good Pareto optimal front. This work will be further extended with other objective function to address other issues in the allocation of DGPV.

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