Optimal Active Power Loss with Feeder Routing Collaborate Distributed Generation Allocation and Sizing in Smart Grid Distribution

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Abstract. The Smart Grid (SG) has widely supported the electric power from the Distributed Generation (DG). It becomes a practical standard to generate the electric power from a renewable energy into the distribution system to compensate for the power demand, especially in the peak time. However, the advancement of the SG continuing with the classical problem of active power loss as the traditional grid. This research aims to solve the active power loss problem by analyzing the elements and study to solve, in the scope of the organization that provides the electrical power. In order to solve the problem, the solutions can be achieved by feeder routing with adjusting cost Dijkstra's algorithm, afterward decided the allocation and sizing of DG by using the Evolutionary Computing (EC) which are Harmony Search (HS), Artificial Bee Colony (ABC), and Particle Swarm Optimization (PSO) algorithms. The experiment evaluates the performance of the algorithm using power flow analysis, Backward/ Forward Sweep Method, on the IEEE 33-bus system. From the experimental result, the PSO provides the best performance. The overall active power loss in the case 3 DGs was reduced from 202.67 to 52.29 kW, representing 74.20% reduction.

Keywords: Minimal active power loss, Backward \ Forward Sweep Method, Harmony Search Algorithm, Artificial Bee Colony Algorithm, Particle Swarm Optimization Algorithm

1 Introduction

A smart electricity system, such as a Smart Grid system, is required in order to better serve a higher power demand. The SG is an integration between a traditional grid and Information and Communication Technology (ICT) from the processes of Generation, Transmission, Distribution, to Consumption. In addition, from power plant electric sourcing, SG must be able to manage an extra power source from a Distributed Generation (DG) as well. Eventhough, the SG distribution has more advanced information but it still suffers the same problem as the traditional grid, the active power loss, that directly affects the electrical power transfer. The problem above was a provocation, causing a significant money to improve the distribution line, distribution transformer, and substation building to accommodate the active power loss [1].

In related research, the defined radial distribution feeder routing with Dijkstra's algorithm to reduces the fixed cost, energy cost, and interruption cost [2]. The other proposed the feeder routing for reducing the cost of energy loss by finding the shortest path to the distribution system [3]. In DG allocation and sizing, the HS was used to solve the problem. The objective was determined by the voltage and the capacitor. In the experiments using the IEEE 33-bus and IEEE 69-bus system to compared the results with the GA and Refine Genetic Algorithm (RGA). The results showed the HS was the best efficient in processing time [4]. The PSO was determine the allocation and sizing of the DG in the objective aimed to reduce the active power loss. In the experiments with IEEE 33-bus system, the result reported the reduces active power loss by determining the allocation and sizing of the DG appropriately [5]. The ABC has chosen to experimental by modified the importance's parameters. In the objective function aimed to minimal the active power loss by experimented with IEEE 33-bus and IEEE 69-bus system that installed the DG .The results modified ABC algorithm can reduce the processing time and number of iterations in the process as well [6].

Mostly the related research defined the objective function with minimal active power loss. Similarly, in this research is conduct to aforementioned objective function .In of order to solve the optimization problem, the experiment is select IEEE 33-bus system and process with feeder routing. After defined routing path, The DG allocation and sizing was experimental by compared the process of HS, ABC and PSO.

2 Proposed methodology

2.1 Adjusting Cost Dijkstra's Method

The Dijkstra's algorithm had the ability to determining the shortest path from a source node to a destination. The shortest distance was calculated from the explicit cost in the graph. On the other hand, the feeder routing is the variable, current and voltage, are change according to the direction of power flow. As a result, the feeder routing still having trouble to finding the exact value of the weight in the graph. In this paper has devised a feeder routing method with the Dijkstra's algorithm for determining the cost to solve the problem. The method has the ability to adjusting the cost, according to the direction of power flow. The cost is calculated from the power flow method. The calculation is repeated until the power variables are stable. The step of adjusting cost Dijkstra's method was composed of:

Step (1) Calculate routing cost. Define the initial values of $I_{KCL,i,t}$ equal ∞ and calculate the weight in the graph by the equation as:

$$C_{i,t} = tan^{-1} \frac{I^2_{KVL,i,t} * X_i}{I^2_{KVL,i,t} * R_i}, \quad (1)$$

where $C_{i,t}$ is the cost of edges number i that flow into node number i in the time t, which calculate by the arctan of ratio between $I^2_{KVL,i,t} * X_i$ and $I^2_{KVL,i,t} * R_i$.

Step (2) Dynamic feeder routing process (Dijkstra's algorithm). The Dijkstra's algorithm was modified by separated for routing as the process to:

(2.1) Find shortest with Dijkstra's algorithm, the process of finding the shortest path from the Dijkstra's algorithm from one source to all destinations.

(2.2) Cut the duplicate edges, by cut the overlapping edges.

(2.3) Eliminate multi-source node, by selecting the node with the lowest total cost to the source node and cut others off.

(2.4) Move the end node to compare active power loss, the results can be separated into two cases. If moving the node and then active power loss reduce, (2.4.1) move the end node to the minimal active power loss source node. Then, recursive to process (2.3) until can't minimal active power loss, the result is (2.4.2) Adjusting Cost Dijkstra's path.

Step (3) Calculate with power flow analysis. The power flow parameters are calculating the new current in time period $t + 1$, in the term of $I_{KCL,i,t+1}$ for the purpose of adjusting the new cost in the term of $C_{i,t+1}$.

Step (4) Find the tolerant between $C_{i,t+1}$ and $C_{i,t}$. In the comparison, if tolerant is more than or equal 0. 0001 (4.1), the cost is adjusted by assigned with $C_{i,t+1}$, and repeat from the second step .On the contrary, if the tolerant is less than 0.0001 (4.2), the result will be the lower active power loss path with the right cost . In the process update the new cost, the improvement will replace the higher cost .Thus, according to the Dijkstra's algorithm, that routing to the lowest cost, the edges will be choose and improved the cost repletely until steady. Finally, the shortest path was defined with the actual cost.

2.2 Problem Formulation

Since the active power loss is depended on the current injected through the branch, that calculated with Ohm's Law. Moreover, the installation of DG effect to change the active power and the current. Accordingly, in this research is defined the objective function in the active power loss as follows:

$$Minimal \ \sum_{i=1}^{n} I^2_{KCL,i} R_i , \quad (2)$$

where the $I_{KCL,i}$ is current (Ampere) of the branch that inject into bus number i, which can be calculated by the power flow method and R_i was the resistance of branch that flows into the bus number i. The Constraints in experiment are included with the parameters of bus and branch that compose of current, voltage, active power, reactive power and appearance power.

$$I_{KCL,i} \leq I_i^{max} , \quad (3)$$
$$V_i^{min} \leq V_{KVL,i} \leq V_i^{max} , \quad (4)$$

where $I_{KCL,i}$ is the current (Ampere) that limit to not more than $I_{MAX,i}$, in the condition of the maximum current flow in conductor type in branch i. The voltage level of the bus must not be higher or lower voltage limit, the lower and upper limits of voltage security range are set to be 0.90 p.u. and 1.05 p.u. [7]. In the term of $V_{KVL,i}$ is voltage (Volt) in bus number i that the value is not less than V_i^{min} and not more than V_i^{max}. In terms of active power and reactive power produced from DG must be limit of the bus. The constraints that shown as:

$$P_{DG,i}^{min} \leq P_{DG,i} \leq P_{DG,i}^{max} , \quad (5)$$
$$Q_{DG,i}^{min} \leq Q_{DG,i} \leq Q_{DG,i}^{max} , \quad (6)$$

where $P_{DG,i}$ is the active power (Watt) in bus number i that supply power in the range of $P_{DG,i}^{min}$ and $P_{DG,i}^{max}$. Similarly, $Q_{DG,i}$ is the reactive power (VAR) in bus number i that supply power in the range of $Q_{DG,i}^{min}$ and $Q_{DG,i}^{max}$. Moreover, the appearance power of DG must not exceed the power requirement in all bus. That can show as:

$$\sum_{i=1}^{i} \sqrt{P_{DG,i}^2 + Q_{DG,i}^2} \leq \sum_{i=1}^{i} \sqrt{P_{Load,i}^2 + Q_{Load,i}^2} , \quad (7)$$

where the equation (7) represents the all appearance power from that generated from DG must not more than all appearance power on the bus.

3. Result and Discussion

The experimental use of data and topology of IEEE 33-bus system [8]. The nodes were composed of the slack bus and load bus are represented by a square and a circle, respectively. In terms of the branch is represented by the directed edges. Graph topology is a directed graph which direction efficacy the power flow by edges. The important variables are composed of static variables in each node consisting of Active Power (P_i), the unit as Watt, Reactive Power (Q_i), the unit as VAR. The variables of edges are contained with Resistance (R_i) and Reactance (X_i) by the couple a unit as Ohm.

The experimentation that aimed to minimal the active power loss was divided into two section. The first was the feeder routing with adjusting cost Dijkstra method and the second, in the consequent process, the DG allocation and sizing with EC. The EC methods, HS, ABC and PSO, were compared. The standard model, IEEE 33-bus system, was chosen and defined the voltage base was 12.66 kV and the apparent power base was 10 MVA, which shown results into the following topics.

3.1 Feeder routing with Adjusting Cost Dijkstra's method.

The accuracy in the calculation of active power loss can be verified with related research that routing on base path. open the tie-switches between the nodes 8-21, 9-15, 12-22, 18-33, and 25-29. All the active power and reactive power were equal 3,715.00 kW and 2,300.00 kVAR, respectively. In the test of routing with base path in this work the power loss was 202.66 kW, that accurate as the other works [17], [9], [20]. After verified the accuracy, next step was adjusting cost Dijkstra method. The feeder routing can be routed to the lower active power path with adjusted $C_{i,t}$ in 4 iterations. From the Dynamic Dijkstra's path was changed topology by the open the switch between node 7-8, 9-10, 14-15, 25-29 and 32-33. The results showed the decision of adjusting cost Dijkstra's had reduced active power loss to 139.56 kW.

3.2 DG allocation and sizing

In the DG allocation and sizing was compared between HS, ABC, and PSO from the Dynamic Dijkstra's path. The DGs were penetrated in the graph as P-Q bus. The nodes of graph on the IEEE 33-bus system were defined as the problem dimensions. The analysis consists of 4 case, accordance with the maximum supply not over than active load, Case-I: 1 DG with the maximum supply 1,000.00 kW, Case-II: 1 DG with the maximum supply 2,000.00 kW, Case-III: 2 DGs with the maximum supply 1,000.00 kW, and Case-IV: 3 DGs the maximum supply 1,000.00 kW. In the first stage using

Case-I and Case-II to compare the results to find the appropriate method, between HS, ABC, and PSO. The parameters of PSO algorithm were composed of the problem dimensions was 32, the weight was 0.3, the swarm size was 100, and the learning factors a_2 and a_2 are 1.5. The parameters of the ABC algorithm were determined by the best result, that consists of nectar source were 32, scout bees were 70, employed bee was 35 and onlooker bees was 35. Similarly, in the parameters of HS algorithm were composed of: Vector of Harmony Size (HMS) was 32, Harmony Memory (HM) was 30, Harmony Consideration Rate (HCR) was 0.9, Pitch Adjust Rate (PAR) was 0.3, and Bandwidth (bw) = 0.01. All methods determination optima's iterations, the processing by iteration until the best cost from objective function don't change more than the tolerance that equal 0.0001 in the 100-previous rounds. The experimentation was 10 times for compared the power loss (best cost), node allocation, DG sizing, optima's iterations, and optima' processing time. The results were compared in the term of mean and standard deviation (σ) values, which shown Table 1.

Table 1. Compare result between HS, ABC and PSO.

Indicators	Algorithms					
	HS		ABC		PSO	
	Mean	σ	Mean	σ	Mean	σ
Case-I: DG allocation node [30]						
Power loss (kW)	93.15	0.4443	92.68	0.0000	92.68	0.0000
DG sizing (kW)	985.35	13.1325	1000.00	0.0000	1000.00	0.0000
Optima's iteration (times)	82.33	14.3233	3.56	1.4181	2.00	0.0000
Optima's processing time (seconds)	7.08	1.2501	11.84	4.5420	1.59	0.0564
Case-II: DG allocation node [25]						
Active power loss (kW)	85.41	0.1835	84.97	0.0000	84.97	0.0000
DG sizing (kW)	1,911.07	51.0407	1762.36	0.0000	1762.36	0.0000
Optima's iteration (times)	47.44	26.6352	82.67	17.9010	42.33	8.6127
Optima's processing time (seconds)	4.06	2.2555	318.75	69.9454	42.00	7.7876

In the Case-I, all methods were install DG on node 30. The HS defined the mean active power nearly optimal capacity (1,000.00 kW), while ABC and PSO can be implemented to the maximum DG capacity. In the terms of reduce active power loss, the ABC and PSO can reduce active power loss equal 92.68 kW (σ=0.0000). The HS was found the mean active power loss on 93.15 kW (σ=0. 4443). In the optima's iteration and processing time, HS was showed very high, mean on 82.33 times (σ=14.3233) and 7.08 (σ=1.2501), respectively. The results of the ABC and PSO algorithm was similarly. The active power loss in both algorithms were optimal in the best cost at 92.68 kW (σ=0.0000) and the DG sizing were presented at 1,000.00 kW (σ=0.0000).

In the Case-II, all methods were install DG on node 25. The DG sizing was not the maximum capacity for reason to made the voltage profile at the node to meted the minimum active power loss. The DG sizing in the HS means at 1,911.07 kW (σ=51.0407), while the ABC and PSO could achieve in 1,762.36 kW (σ=0.0000). In terms of active power loss reduction, the ABC and PSO can get better by in the both cases equal 84.97 kW (σ=0.0000). In the optima's iteration and the processing time, the PSO algorithm was the best performance at 42.00 seconds (σ=7.7876).

In contrast, the ABC and PSO had given the better results in the processing, especially PSO. In the first section the PSO algorithm was the best performance. In the second section, the consequent experiments, according to Case-III and Case-IV has selected PSO. The empirical model based on the previous parameter values of tolerance and the number of iterations required. The experimented was conducted in 10 times, which can show results as Table 2.

Table 2. The result of experimented with PSO in Case-III and Case-IV.

	Case-III: DG allocation nodes [8 30]		Case-IV: DG allocation nodes [8 24 31]	
Performance indicators	Mean	σ	Mean	σ
Active power loss (kW)	70.56	0.0000	52.29	0.0000
DG sizing (kW)	[920.74 1000.00]	-	[899.42 994.48 962.50]	-
Optima's iteration (times)	45.56	7.3492	69.78	10.4350
Optima's time (seconds)	48.34	9.9009	71.79	10.3602
Active power loss (kW)	70.56	0.0000	52.29	0.0000

In the Case-III, the DG was installed in the node 8 and 30, with the total sizing of 920.74 and 1,000.00 kW. The mean active power loss was 70.56 kW (σ=0.0000). In terms of the processing performance, the number optima's iterations and processing time to were 45.56 times (σ=7.3492) and 48.34 seconds (σ=9.9009), that showed in Fig. 1.
The final case, Case-IV, the results showed the DG allocation will be installed in the node 8, 24 and 31 with the sizing were 899.42, 994.48, and 962.50 kW. The active power loss reduced to 52.29 kW (σ=0.0000). In terms of efficiency of processing, was stable inferior to 1 DG. In the optima's iteration and processing time, were 69.78 times (σ=10.4350) and 71.79 seconds (σ=10.3602), respectively.

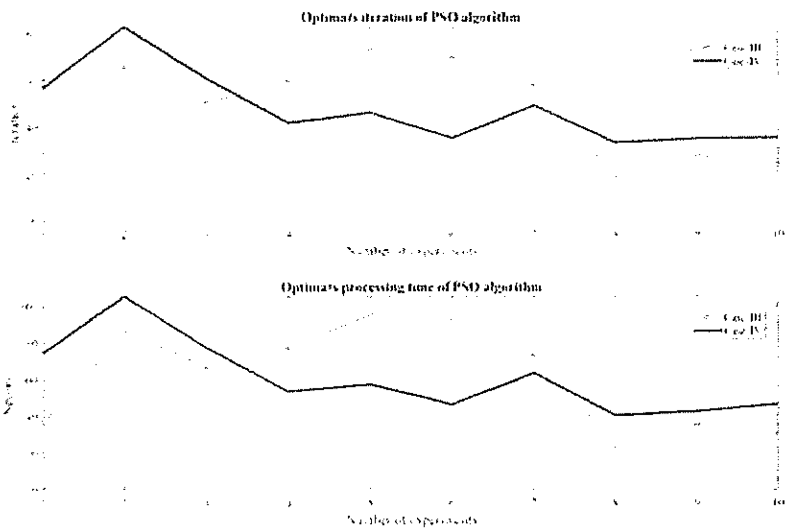

Figure 1. The Optima's iteration and processing time with PSO.

In comparison, the results in the Case-III and Case-IV, was defined allocation and sizing were determined exactly. In contrast, the values of optima's iterations and processing time were not stable due to the σ value. In addition of defining the objective function to minimal the active power loss, can be achieved effectively. In the best case, the process of feeder routing and optimization the DG allocation and sizing in Case-IV, the active power loss was reduced from 202.67 to 52.29 kW, representing 74.20%. The steps of minimal active power loss from the feeder routing and reduced to 139.56 kW and the consequence with DG allocation and sizing by PSO was reduce to 52.29 kW.

4. Conclusions

The research aimed to analyzed the active power loss problems and found the variety of possible solutions. The solution of feeder routing with adjusting cost Dijkstra' method, consequently DG allocation and sizing with PSO, can reduce active power loss as well. The approach of the feeder routing with Dijkstra's algorithm can be applied to adjusted the cost in the concept of dynamic for the match the real power flow. After adjusted the cost, the experimentation was reconfiguration feeder topology, that implemented effectively. Consequently, the DG allocation and sizing were the experiment by the EC for reducing active power loss. The experimented found that PSO algorithm could determine the proper location and sizing of DG. Both methods have solved the active power loss problem in a coherent system. However, this research work can be further studied to cover a multi-objective function by adding Power Factor for a more effective measurement. Furthermore, the experiment data will adjust to time series, with historical load and supply from the real feeder.

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