Optimum Location of DG for Loss Reduction with Ant Colony Algorithm

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Abstract: The ability of the Distributed Generation (DG) to solve problems such as power system deregulation and power demand problems appropriate to its purpose, which is to inject electricity in a distributed manner at a point close to the load, causes the distributed generation to become the latest trend in electricity generation technology. Proper position of distributed generation is necessary in order to achieve maximum benefit from DG, which could be due to an incorrect allocation of DG sources to the power network would not only result in increased power losses, but could also jeopardize the operation of the system. This paper introduces an ACO-algorithm for optimal location of DGs using a real network in one of a rural area of Malaysia. The method is used to determine the effectiveness of DG by comparing the losses of power and the improvement of the voltage profile. As for the confirmation to the ACO method, another method known as brute force method is use to compare the data gain as validation purposes.

Keyword— DG, ACO, Power losses, Voltage profile, optimisation

1. INTRODUCTION

Supply, transmission and use of electrical power is the process in which the electrical system is identified as a network system with an electrical component [1]. The increased interest in DG is due to the modernization of the power grid and the tight restriction on the building of new bulk substations and transmission lines. That may be attributed to the growing of society, which has contributed to a high level of electrical energy use. The increase in demand for energy allows the distributed generation to emerge as a new option for the supply of electricity to the consumer. DG is a concept that refers to electricity generation near the point of consumption [2], [3]. In this advanced technology era, demand for electricity continues to rise with an increase in industrialization and population, especially in rural areas. The reason for this is that the substation power supply is a radial network in rural areas, therefore the demand for electricity continues to increase as the population increases. The configuration of the radial network that is intended to be fed from one end and the loads are connected to the other end. The arrangement of the radial network will cause the voltage to decrease as it leaves the substation [4].

Constraints on the new construction or expansion of existing large conventional power plants have exacerbated environmental issues and the drawbacks of modern power stations. These problems paved the way for a new technology known as distributed generation to address the supply and demand gap problem [5]. Typically, distributed generation is a small unit that produces electricity between 1KW and 50MW. The architecture of this energy-size system is such that it can be installed...
near to the consumer or the electrical distribution network. Suitable with its functionality, the presence of power generation distribution is designed specifically to promote system efficiency such as power quality, stability, power flow, voltage profile, reliability and protection. Without question, the implementation of DG could offer major benefits in the field of power distribution, but, like other technologies, DG also has its own advantages and disadvantages. Installation of DGs must take place at a particular and precise location in order to allow maximum use of DGs [6]. This is the problem for the engineer to solve, as the improper installation of DG could create an undesired result that could jeopardize the entire system. Insufficient allocation of DGs could lead to increased losses, harmonics and voltage flickering of the distribution network [7].

Several algorithms and methods have been developed based on the previous research papers to address the allocation of DG to the Distribution Network (DN). The variations between these algorithms relate to the formulation of the problem, the intended technique and their assumptions. These methods mentioned include Genetic Algorithm (GA), Grey Wolf Optimization (GWO), Ant Colony Optimization (ACO), the NEPLAN Software, and Imperialist Competitive Algorithm (ICA). GA have been used to reduce network losses and regulate the voltage [8][9][10][11], GWO is used to improve the voltage and reduce active power loss [5], the NEPLAN Software is used to determine the location of DG and optimum location of switch pair considering the power loss at each bus [12][13][14] , ACO is utilised for cost and power loss minimization [6] and ICA is used for enhancement of voltage profile and power loss reduction [5][15].

In this paper, ACO is implemented in one of Malaysia’s rural network systems and the scientific contribution of this paper is to prove the algorithm can be implemented in the network, that power loss is minimized, that the voltage profile can be improved and DG's optimal position can be achieved.

The paper’s organization is as follows. Section II described the methodologies of the research and flow of the research to achieve the objective. Section III discussed about the experimental result of the optimal location of DG using ACO. Lastly, section VI concludes on the proposed methods and future suggestions of this study.

2. MATERIAL & METHODOLOGY

General Aspect. The ACO algorithm is a class method that is used to solve complex combination optimization problems. The ACO algorithm method performs the scheduling of three tasks. The first step consists of the initialization of the pheromone route. In the iteration (second) step, each ant constructs a complete solution to the problem according to the probabilistic state transition law. The state change law depends primarily on the state of the pheromone. The third stage changes the quantity of pheromone where the pheromone update laws are implemented in two stages. The first stage is the evaporation process where a fraction of pheromone evaporates and then there is a reinforcement process, increasing the amount of pheromone on the path with high quality solutions. The method is iterated until the criterion of stopping is reached.

Designation of the ACO (Matemathically):

1. The Initialisation of Pheromones [5]
   \( T_{ij}(0) \) refers to the initial pheromone in each pathway. During this process, the \( T_{ij}(0) \) pheromone concentration between cities i and j is 0.

2. Kth is refer to the ant probability (K= 1,2,3,...) choosing the next path through this equation[4]:
   \[
   P_k = \frac{\tau_{ij}(t)\eta_{ij}^{\alpha}}{\sum_{j} \tau_{ij}(t)\eta_{ij}^{\alpha}}
   \]
   if \( j \in \tau(k) = 0 \) otherwise
   \( ij \)

   Where \( \tau(t) \) is the pheromones left between i and j
\(\eta_{ij}\) Is the expectation the path that choose by ant through i and j

Where \(\eta_{ij} = \frac{1}{d_{ij}}\)

3. Pheromone update [5]:
Total pheromone of each is updated by this equation

\[
\tau_{ij}^{k+1}(t) = (1 - \rho) \times \tau_{ij}^{k}(t) + \Delta \tau_{ij}
\]  

Where \(\rho\) is positive number between 0&1

2.1. Formulation of the problem
Real power losses without DG[4] calculated by using (3). Simple distribution network shown in Figure 1. The network consists of two substations without DG.

\[P_{loss} = \sum_{i=1}^{N} (I_{L_i}^2) R_i\]  

Where \(I_{L_i}\) = line current
\(N\) = total branch number in system
\(R\) = resistance in i
\(I_d\) = current load demand

Where \(I_{L_i} = I_d\)

![Figure 1. Example of distribution network without DG](image1)

Line power losses indicated by the (3) could be reduced by reducing the branch current of the distribution network by adding the DG to the distribution network as shown in Figure 2. DG located at substation number 2. From the basic (3), following Kirchhoff Current Law, power loss for the network calculated by using (4). By assuming DG located as shown in Figure 2.

\[P_{loss} = \sum_{i=1}^{N} (I_{L_i}^2 - I_{g}^2) R_i\]  

![Figure 2. Example of distribution network with DG](image2)

The algorithm is designed to reduce the total power loss of the network while meeting certain device variable constraints. The inequality constraint are the real and reactive power limits and voltage limits

\[V_{min} < V_j < V_{max}\]
Where \( j \) is the bus number of distribution network

\[
P_{\text{min}} < P_{\text{dg}} < P_{\text{max}}
\]

\[
Q_{\text{min}} < Q_{\text{dg}} < Q_{\text{max}}
\]

The DG output in KVA real and reactive power should satisfy the limit.

**Improving Voltage:**

\[
V_1 = E - IZ_1 \tag{5}
\]

\[
V_2 = E - (IZ_1 - I_2Z_2) \tag{6}
\]

\[
V_i = E - \sum_{i=1}^{n} I_iZ_i \tag{7}
\]

As the load are connected away from substation voltages are decrease at the load.

### 2.3. ACO application to allocate DG

The equation (8) represents a stochastic model of the movement of ants, which assigns the probability of each ant to choose a direction.

\[
P_i = \frac{(m_1 + k)^h}{((m_1 + k)^h + (m_2 + k)^h)} \tag{8}
\]

Where:

- \( m_1 \) & \( m_2 \) are the routes 1 and 2 that the ant has recently used.
- \( k \) & \( h \) are constant define according to problem characteristic

**Transition Rule.** The action of each ant performing its travels is mainly determined by a transition rule which is restricted by two factors which are visibility and the effect of pheromone. The rule is shown through this equation:

\[
P_i = \alpha \cdot (1 - \beta) + \beta \cdot (1 - \alpha) \tag{9}
\]

Where \( P_i \) is the probability of a DG connected to bus \( i \) of the system.

\( \alpha \& \beta \) are the parameter algorithm represent influence pheromone & visibility typically values \( \alpha=0.9 \) & \( \beta=0.1 \). Eventually, a roulette algorithm is implemented such that each of the possible solutions is likely to be chosen.

**Pheromone.** There are two categories of matrices \( \tau \) that the pheromone implement in the algorithm. This matrices apply in order to determine the location (bus) of the DG and DG size. The first matrix referring to DG position that has a size of number of bus (NB) row, where NB is the total number of device busses and \( m \) columns, where \( m \) is the number of DGs to be located. The second pheromone matrix makes it possible to find optimal DG sizes. Every column in the array represents a device bus, and each row corresponds to a potential size value to locate.

| DG position |
|-------------|
| X X X |

| DG size |
|---------|
| X X X |

Where \( X \) is the power losses
**Visibility.** Visibility $\eta[i]$ serves as a mechanism that guides ants in the creation of good solutions. As for the pheromone matrix, the visibility is applied to each bus $I$ in the row vector $\eta[i]$ with the column $c$. Every column $I$ is aligned with a specific generation value:

1. The location of DG. In particular, the proposed DG location algorithm is used to measure the lines connected to each bus and to determine a certain bias (favouritism) the loss values in those lines are calculated. In this case, the node with the highest number is the one with the best chance of being selected.
2. DG Scale. In the case of scale, no particular approach was used to support any kind of solution, and it was only assumed to assign equal chance to all solutions via a normal function.

**Pheromone Update.** Two operations are taking place during pheromone update:

1. The first pheromone update occurs in every iteration. At this point, both pheromone matrices are completely changed with the concentration on ants produced during this iteration.

   \[
   \tau_{ij} \leftarrow (1 - \rho) \cdot \tau_{ij} + \sum_{k=1}^{m} \Delta \tau_{ij}^k
   \]  
   \[(10)\]

   Where; $\rho$ is the evaporation rate  
   \(\tau_{ij}^k\) is the amount of pheromones left by the ant $k$ in $(i,j)$ edge and

   \[
   \Delta \tau_{ij}^k = \begin{cases} 
   \frac{\text{losses}_{w/o GD}}{L_k}, & \text{if } (i,j) \text{is used} \\
   0, & \text{in other cases} 
   \end{cases}
   \]  
   \[(11)\]

   where: $\text{losses}_{w/o GD}$ is a constant in system correlating to system power loss without DG. 
   $L_k$ is the cumulative length of the direction the ant follows fitness function

2. The update will take place at the end of each iteration. In order to facilitate a quest in the particular area of the problem, the change will only be carried out with the best overall solution. To do so, the component of size and location are increased by 5% for each iteration while retaining the best overall solution.

The main steps of the proposed ACO algorithm are shown below.

- **Step 1 (search space):**  
  The design is a framework that is ideal for seeking a solution to the problem. In this case, the search space is the 18 bus of the DN’s real rural network. Ant must read the DN data prior to the implementation of DG. The solution to the problem will be generated after the ants have completed their decision-making process for the sub-route forming a path.

- **Step 2 (ACO initialization):**  
  Beginning with the ACO algorithm, the constant value $\tau_0>0$ are initialize from the pheromone values of the edges in the search space . Initialisation causes the ants to choose their paths randomly and thus the solution space is more efficient.

- **Step 3 (ant dispatch):**  
  In this process, the ant is dispatched and the solution is built on the basis of the pheromone level on the edges. In this step, each ant will start a tour of the home colony and choose one of the states in the next stage to travel according to the following equation (7). After each ant end the tour ends, a new DG placement solution is created, which must be evaluated using the fitness function.
Where the $\tau_{ij}(t)$ is the total pheromone deposited at edge $ij$ with iteration $t$ and $\Delta i$ is the set of available edges which ants can select in state $i$.

- **Step 4 (fitness function):**
  In this stage, the fitness tour created by the ants is evaluated by their fitness function. The fitness function of the problem is defined as the power load flow plus the penalty factor for the infeasible solution. In order to speed up the convergence properties of the algorithm and, at the same time, to use the details that might still be useful to the rejected tours. This penalty tour increased from zero to a very high value across iterations.

- **Step 5 (pheromone update):**
  The goal of the pheromone value update is to increase the pheromone value of the solution components found in the fitness function solution. Furthermore, from a practical point of view, pheromone evaporation is required in order to avoid the convergence of an algorithm that is too fast towards a sub-optimal area. It introduces a useful method of forgetting, preferring the discovery of new areas in the search space. The equation for update pheromone are as equation (10) & (11).

- **Step 6 (convergence determination):**
  Step 3 to 5 will proceed until the number of the iteration counter exceeds the predefined maximum number which is calculated experimentally. The best tour to choose from among all iterations means an optimal DG solution.
The purpose of algorithm is shown in the flow chart of the overall research work in Figure 3.

3. MATHEMATICALLY CALCULATION OF DG

Equation (12) and (13) shown a calculation of P if the network having 4 loads as shown in Figure 4.

Figure 4. Example of network with 4 load, DG located at substation no 2
3.1. Brute Force Method

In order to ensure that the ACO result is accurate, the data gain from the ACO method is compared to another collection of data gain by using the brute force method. The brute force method could be considered as simplest meta-heuristic method. It is also known by a different name, such as exhaustive search, generation and testing or direct search. It is an exhaustive evaluation of the target function with all possible input values. This type of approach is useful in order to solve the discrete type of problems, such as finding an optimum allocation of DGs in the network. This method is considered to be the most effective options available because of its ability to deliver the most reliable result. That is because brute force is a method that will consider any possible value in order to obtain a certain outcome. Although it is not an efficient solution approach, due to if the number of potential candidates increases, the number of possible solutions will increase rapidly. Therefore, the method of brute force is only applicable to a small number of candidates but the results obtain are still accurate due to all possible tests.

Apart from its simplicity and precision, the main reason for proposing brute force in this project is to confirm that the performance generated is identical to the main method used by ACO as an optimizing tool to locate DG. Using this method, it will make it possible for researchers to have a complete audit of the results. Although brute force is a non-artificial intelligent method, this confidence stems from the fact that brute force is a method that uses all potential candidates to be tested to produce ideally matched to a single or unique solution outcome.

According to the brute force rule, the total number of possible conditions could be determined as follows.

\[ PC = \text{BusNo}^{\text{GenNo}} \]  
(14)

Where
- \( PC \): possible condition
- \( \text{GenNo} \): number of generator for optimization
- \( \text{BusNo} \): the number of distribution buses in network

4. RESULTS & DISCUSSIONS

Output results of the proposed algorithm are obtained from the program MATLAB. The distribution network of one of the rural cities in Malaysia shown in Figure 2 was used to test the efficiency of the algorithm. The system uses a regulated voltage of 11 kV, applied power of 100 MVA without voltage regulators and a bank capacitor installed. The power factor is 0.85 according to the standard used by Tenaga Nasional Berhad (TNB). Total net load is 11.64 MW, spread across three categories of customer that are industrial, commercial and residential consumers. The optimum position of DG sources in the distribution system is evaluated using the proposed ACO-based algorithm. The final solution is also compared to the initial system condition without DG. In order to confirm that the data gain from the ACO method is correct, the data gain from using the brute force method is use to compare as the confirmation that the specific bus is suitable to locate the DG. Through the ACO method the outcome gain shows that there is a significant improvement show in power loss outcome after DG is implemented via ACO method. The data resulting from power loss after DG has been installed by ACO method is shown in Table 1. In this case the algorithm was performed a total of 5 ant generation with 20 iteration in order to gain the optimal location of the DG. The confirmation of the data gain from ACO to show that the suitable place to locate the DG is verified with the data gain.
from the Brute Force which is shown in Table 3. The product of the graph line showing the correct DG allocation position through the power loss improvement via before and after the DG is install is shown in Figure 3 & Figure 4. In the figure it can be seen that the installing the DG at the suitable location could improve the total power loss. This can be seen at bus 8 where its shows that it has significant improvement of power loss on both real power and reactive power. This result is further verified when the data of graph line of power loss from Brute Force method shown in figure 5&6 also produce the same result where it show that bus 8 is the most suitable place to locate the DG.

Table 1 shows real power loss at each bus before and after DG is installed via ACO. The suitable Dg position selected by ACO at bus 8

| Bus | Real Power Loss Before DG | Reactive Power Loss Before DG | Real Power Loss After Install DG | Reactive Power Loss After Install DG |
|-----|---------------------------|------------------------------|-------------------------------|-------------------------------------|
| 1   | 12.3851                   | 17.0510                      | 4.3830                        | 6.0343                              |
| 2   | 4.4666                    | 6.3150                       | 1.4592                        | 2.0630                              |
| 3   | 7.8007                    | 10.7386                      | 2.3608                        | 3.2499                              |
| 4   | 6.1665                    | 8.4890                       | 1.7691                        | 2.4354                              |
| 5   | 3.4363                    | 4.7355                       | 0.9965                        | 1.3733                              |
| 6   | 2.5262                    | 3.4805                       | 0.8462                        | 1.1659                              |
| 7   | 1.9293                    | 2.6559                       | 0.9190                        | 1.2651                              |
| 8   | 1.2352                    | 1.7004                       | 1.0621                        | 1.4621                              |
| 9   | 1.3902                    | 1.9138                       | 1.3902                        | 1.9138                              |
| 10  | 0.1931                    | 0.2658                       | 0.1931                        | 0.2658                              |
| 11  | 0.6966                    | 0.9590                       | 0.6966                        | 0.9590                              |
| 12  | 0.0773                    | 0.1064                       | 0.0773                        | 0.1064                              |
| 13  | 0.0193                    | 0.0266                       | 0.0193                        | 0.0266                              |
| 14  | 0.0204                    | 0.0280                       | 0.0204                        | 0.0280                              |
| 15  | 0.0309                    | 0.0426                       | 0.0309                        | 0.0426                              |
| 16  | 0.0137                    | 0.0189                       | 0.0137                        | 0.0189                              |
| 17  | 0.0034                    | 0.0047                       | 0.0034                        | 0.0047                              |
| TOTAL| 42.3910                   | 58.5316                      | 16.2410                       | 22.4148                              |
Figure 6. Real power loss in case of the real rural network before and after using ACO.

Figure 7. Reactive power loss in case of the real rural network before and after using ACO.

Figure 6 and 7 shows the power loss graph line before and after DG is implemented via ACO method.

Table 2 show the confirmation of the result gain from ACO and Brute Force method. Extend your table explanation here.

| Method                        | Position of DG at Bus suggested from the method | Size DG (kW) | Total Power Loss (kW) |
|-------------------------------|-----------------------------------------------|--------------|-----------------------|
| Without DG (Normal condition) | NA                                            | NA           | 42.3910               |
| Brute Force                   | 8                                             | 710          | 16.2410               |
| ACO                           | 8                                             | 710          | 16.2410               |

Figure 8 and 9 shows the line graph after using DG is locate in the network. Based on the data gain it shows that the most suitable place to locate DG is at bus 8 this is because there is a significant improve in real and reactive power losses at bus 8 compared to when the DG is located at other buses.
5. CONCLUSION

This paper introduced a method for finding the optimum position of the distributed generation. In this paper, an algorithm is proposed to be tested in one of the rural real network in Malaysia where the specialization of ACO was used as an alternative solution method to solve the optimizing problem. In order to observe the efficiency of the DG positioning, a collection of data on power loss and voltage stability was taken, reported and compared with the data set before the DG was integrated in the network. From the data gain shows that implementing DG into the network could improve the DN in term of power loss and voltage stability which shows that the DG is effective to reduce a power in a case study network. Furthermore, the objective of this project to gain optimal allocation for DG using ACO is achieved. The result from the ACO method is confirm through another algorithm via Brute Force which produce the same result as the ACO method does.

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