Distribution Power Loss Minimization via Distributed Generation, Capacitor and Network Reconfiguration

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Abstract

This paper presents a solution to solve the network reconfiguration, DG coordination (location and size) and capacitor coordination (location and size), simultaneously. The proposed solution will be determined by using Artificial Bee Colony (ABC). Various case studies are presented to see the impact on the test system, in term of power loss reduction and also voltage profiles. The proposed approach is applied to a 33-bus test system and simulate by using MATLAB programming. The simulation results show that combination of DG, capacitor and network reconfiguration gives a positive impact on total power losses minimization as well as voltage profile improvement compared to other case studies.

Keywords: power loss minimization, distributed generation, capacitor, network reconfiguration, artificial bee colony

1. Introduction

Increased of power losses in distribution system is a major challenge that needed to be addressed by the utilities. With demand for electricity is expected to intensify in the future, the utilities are forced to find ways to reduce the power losses, hence increase the system efficiency. Furthermore, it also could push all the equipments to operate at maximum loading that could lead to equipment failure. Revamp the existing power system is not a practical solution that should be done by the utilities due to the increment in the investment and capital costs. Therefore, researchers had introduced several approaches that can be implemented without having a major construction to the existing system such as Network Reconfiguration (NR) process, installing capacitor and insertion of Distributed Generation (DG). All of these solutions have been widely used by the researchers/engineers to mitigate power losses that existed in the distribution network.

The NR works by controlling ON/OFF status of switches that pre-installed at each distribution lines. The reason for this approach is to reroute power flow at distribution network hence reduce the power losses [1]. There are two types of switches installed in the distribution system which is tie-switches (normally open) and sectionalize-switches (normally close). Besides controlling the switches, it also needs to make sure that the distribution circuit still maintains the radial connection. Even though the process of NR looks simple, selections of ON/OFF combination are a complex decision-making process that needs to be done thoroughly. To handle this kind of situation, a proper algorithm should be used. Traditionally, the NR is solved by using heuristic search techniques, and one of the early adopters to solve this problem is Merlin and Back in 1975 [2]. They proposed a branch-and-bound method which was later modified by Shirmohammadi and Hong [3] 14 years later. With the emerging of artificial approach, meta-heuristic methods become more popular to solve this NR problem. Some examples of these methods are Genetic Algorithm (GA) [4], Particle Swarm Optimization (PSO) [5], tabu search [6] and Ant Colony Search (ACS) [7].

Another approach of reducing the power losses is by installing capacitor. The objective of this approach is to inject certain amount of reactive power into the distribution system, to improve the voltage profile and later reduce the power losses. Similar to the NR approach, there are many techniques that had been proposed by researchers to solve the capacitor problem. These techniques can be categorized into four which are analytical, numerical, heuristic and artificial intelligent [8] had reviewed in details regarding capacitor placement conducted by previous researchers. Also, comparison of different methods to determine capacitor placement are performed. Basically, the solution of capacitor placement is done separately. The location of the capacitor is done by using sensitivity analysis, whereas, for the size of the capacitor is calculated using meta-heuristic methods such as PSO [9], ABC [10], Plant Growth Simulation Algorithm (PGSA) [11], and GA [12]. However, this will force the solution to trap in local optimum (meaning not the best solution) due to pre-determine of location by using sensitivity analysis is not considered the best value of size. To alleviate such problem, some of the authors had determined locations and sizes of capacitors simultaneously that usually done by using meta-heuristic [13]. In term of solutions for both approaches, determination of sizes and locations for capacitor simultaneously gives better results as compared to separate analysis [13].

Besides aforementioned methods to minimize the losses, integration of DG with distribution network is another popular approach chosen by the researchers. There are many research papers had been published to see the impact of installation of DG. Among the advantages offered by the DG are power loss reduction, voltage profile improvement and stability index enhancement [14]. However, all of these benefits are not obtained if the calculation of size and location for the DG is not properly determined [15]. Similar to the capacitor, the same methodology can be used to determine optimal location and size of the DG. Some examples of methods that had been applied to solve DG coordination are Evolution Programming (EP) [16], PSO [17], ABC [18], GA [19] and Firefly Algorithm (FA) [20]. In addition, authors [21] proof that coordination for location and size of DG done simultaneously compared to separate analysis (location is determined first before calculation of the size) gives better results.

Generally, most researchers focus only on either the NR or capacitor installations or DG allocation. However, the solution is still less effective in reducing the power loss. Therefore, there are a number of suggestions put forward by researchers to combine these methods to get better results. The authors [22, 23] suggested a combination of the NR with the capacitor. Later, a combination of DG and capacitor is introduced [24, 25] as well as a combination of DG and NR [26, 27]. All of the combinations give better power loss reduction compared if a single method is used. Recently, several papers have proposed to solve these three methods, simultaneously. The authors solved by using tabu search method [28]. They successfully showed that combination of DG, capacitor, and NR gives better results. However, this solution still not give best results due to the authors already pre-determined the locations and sizes of DG and capacitor. This will lead the solution to trap in a local optimum. Similar in [29], they determined the location for both DG and capacitor by using sensitivity index to reduce the search space. The authors in [30] also already assumed the DG and capacitor installed. They solved the solution by using PSO. Overall, the combination of all these three methods provides better power loss reduction. However, in the above-mentioned references, they still not fully determine all parameters (switches for NR, locations, and sizes for DG and capacitor) using a single method. Therefore, this paper proposes a solution to solve all parameters by using ABC in a single computation.

The rest of the paper is organized as follows: Section 2 provides a methodology to solve the proposed method. Section 3 presents the results and discussion for different case studies. The last section concludes this research paper.

2. Research Method

As discussed in the previous section, there are several methods that had been applied to determine the value of switches, location, and size for both DG and capacitor. Improper determination of these parameters will lead the solution to trap in local optimum, which is not the best solution. Since the combination of these approaches is complex and difficult to solve, thus, meta-heuristic is selected due to simplicity and robustness [31]. The word "meta" actually

referring to the word "beyond" based on the Oxford dictionary, while the word "heuristic" is a process to learn something by them. Basically, meta-heuristic can be categorized into two groups based on the initial solution which are trajectory and population. Some examples under population-based for meta-heuristic are: GA, PSO, ABC, ACS, and FA. For this research paper, the ABC method is selected due to simplicity and only has two parameters that needed to be tuned.

The ABC was introduced by Karaboga [32] in 2005. The concept of this optimization is following the behavior of a swarm of bees to find foods, which involved four stages as illustrated in Figure 1. For tuning process, a size of colony and limit is determined by using trial-and-error method before the start of the optimization process. The ABC process starts with initialization process, which all the bees randomly find the food location (parameter value that needs to be optimized). All the information wil be store and evaluate by using Equation 1. All these information will be used by employed bees during the second stage to find new food location by using Equation 2. Similarly for the third stage, onlooker bees will use the information obtained from the employed bees and find new food location, but, the probability the foods are chosen by the onlooker bees depends on the value of nectar by using Equation 3. For the last stage, one bee that is known as scout bee will find a new food location once the food is depleted. All the process is repeated until maximum cycle acieved.
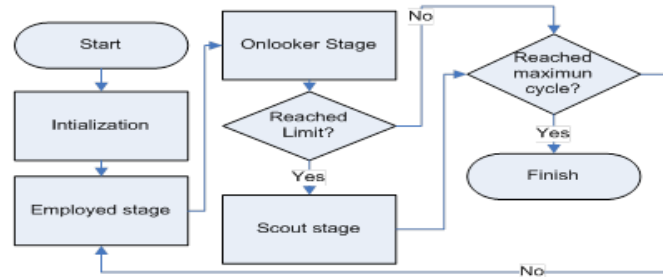

Figure 1. Flow chart of ABC

$$F_i = \frac{1}{(1 + Obj.Func_i)} \tag{1}$$

where F_i is the fitness for the objective function and *Obj. Func*$_i$ (Total power loss) is the target of the study.

$$x_{ij}^{new} = x_{ij}^{old} + range(0,1) \times \left(x_{ij}^{old} - x_{kj}\right) \tag{2}$$

where x_{ij}^{new} and x_{ij}^{old} are the new and previous value of variable (either switches or DG location or DG size or capacitor location or capacitor size), respectively. x_{kj} is a neighbor value that is selected randomly from j^{th} dimension and *range*(0,1) is a random value between 0 and 1.

$$prob_i = \frac{F_i}{\sum_{i=1}^{N} F_i} \tag{3}$$

where *prob*$_i$ is the probability, and *N* is a number of employed bees.

3. Mathematical Formulation

Main target of this research is to see the impact of power loss reduction when harmonization between switches, location, and sizes for both DG and capacitor are done. Therefore, Total Power Loss (TPL) in the distribution system is selected as a main target

(objective function) in the ABC optimization. The objective function in the system is formulated as in Equation 4.

$$TPL = \sum_{L=1}^{n} \left(|I_L|^2 \times R_L \right) \tag{4}$$

where L is a number of branches, I_L is branch current, and R_L is branch resistance.

Besides achieving the main objective to reduce the power losses, optimal selection of parameters that has been determined by the ABC must fulfill all constraints. This process is an important procedure that needed to be observed during optimization process so that the solution will not violate any limits. All constraints that are used during optimization process are listed:

Size of DG constraint:

$$0.3\,MW \le P_{DG} \le 3MW \tag{5}$$

where P_{DG} is the size of the DG. For this study, the minimum and maximum size of DG is 0.3 MW and 3 MW, respectively.
a) Power balance constraint:

$$P_{DG} + P_{Substation} = P_{Load} + TPL \tag{6}$$

The summation of total power supply by substation and power output from the DG must be equal to the total size of load plus total power losses.
b) Radial circuit constraint:
For each of network reconfiguration process, the network must maintain its radial circuit.
c) Size of capacitor constraint:
To ensure the selection of size for the capacitor is of practical value. Only five values will be chosen (300, 600, 900, 1200 and 1500 kVar).
d) Voltage bus constraint:

$$0.90 \le V_n \le 1.05 \tag{7}$$

where n is a number of buses in the distribution system.

4. Results and Analysis

Several case studies have been used as in Table 1. For Case 1, the simulation is done without any approaches imposed. Basically, the power loss during this case is the original power losses for the test system. For the second case (Case 2), capacitor is considered to see the impact on power loss minimization. Both of location and size for the capacitor are determined by using ABC optimization. On the other hand, Case 3 only considers network reconfiguration process by selecting the optimal topology (by switch ON/OFF of the switches). For Case 4, the process is similar like the Case 2, but instead of the capacitor, the DG will be used. For this research, all DG are assumed to operate in Power-Voltage (PV) mode. For second last case (Case 5), a combination between the DG and capacitor is investigated. Lastly, for Case 6, all approaches will be combined and determined, simultaneously.

All the above case studies are tested on the test system as shown in Figure 2. The system is connected to 132/12.66 kV substation having 33 buses and 32 lines with 3.715 MW and 2.300 MVar of the total load. For NR purposes, switches 33, 34, 35, 36 and 37 are assumed to be tie switch (initially the switches are open). All the data of this system can be obtained in [33].

Table 1. Various Case Studies

| Case	Description	Case	Description
1	Original test system without any NR process, DG, and capacitor installation, simultaneously.	4	Determine optimal values of location and size for DG, simultaneously.
2	Determine optimal values of location and size for capacitor on test system.	5	Determine optimal values of location and size for both DG and capacitor, simultaneously.
3	Determine optimal network topology of test system by using the NR process.	6	Determine optimal network reconfiguration together with optimal location and size for both DG and capacitor, simultaneously.
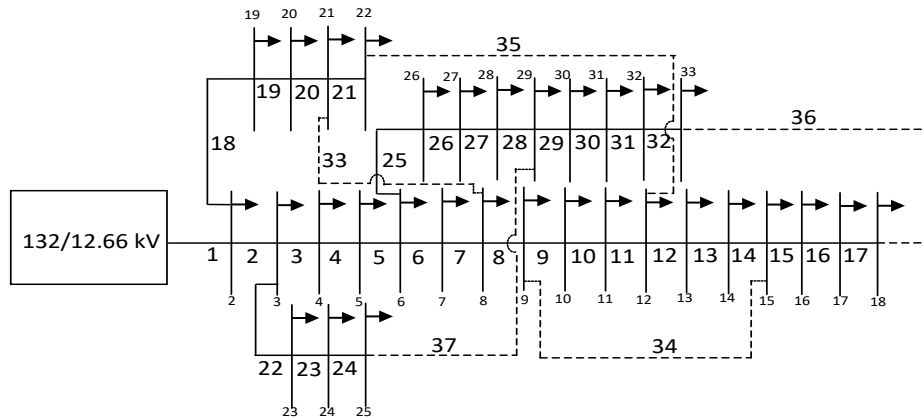
Figure 2. Original 33-bust system including optional switches

Table 2 shows the comparison between all cases in term of power loss reduction, open switches, statistical analysis and optimal size and location for both DG and capacitor. Original total power losses in the system are 203.19 kW as shown in Case 1. Case 2, 4 and 5 have similar open switches with Case 1 as there is no NR process imposed. For the power loss reduction, it can be clearly seen that Case 6 give higher power loss reduction in total power losses in the system (34.90 kW) when the combination of DG, capacitor, and NR is done. The second higher of power loss reduction is Case 5 at 48.31 kW. It's then followed by Case 4, 2 and 3 at 61.55 kW, 142.61 kW, and 143.93 kW, respectively. This shows that the combination of two or three approaches can give superior results as compared to a single approach (either DG only or NR only or capacitor only). Overall, the simultaneous solution between the DG, NR and capacitor can give superior results.

Table 2. Summary of results for all case studies

	Descriptions	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
	Control Parameters (NOB=Number of Bees, LMT=Limit)	-	NOB=40, LMT=50	NOB=10, LMT=30	NOB=40, LMT=50	NOB=40, LMT=150	NOB=100, LMT=550
	Branch Opened	33, 34, 35, 36, 37	33, 34, 35, 36, 37	7, 9,14,31,37	33, 34, 35, 36, 37	33, 34, 35, 36, 37	9,22,26,33,34
For DG	Optimal Location	-	-	-	6	6	29
	Optimal Output Power (MW)	-	-	-	2.47	2.51	2.12
For Capacitor	Optimal Location	-	30	-	-	30	5
	Optimal Size (kVar)	-	1200	-	-	1200	600
	Total Power Loss (kW)	203.19	143.93	142.61	61.55	48.31	34.90

Figure 3 illustrates voltage profiles for all cases. All cases give better voltage profiles as compared to Case 1 (base case). Also, all the value of voltages at each bus is within the limit. For Case 2 and 3, there are no significant improvement can be obtained compare to the case 1 due to no active power injection to the system that can contribute better voltage improvement. This can showed in case 4 where injection of active power from the DG give better voltage profile at almost all buses when compare to case 1, 2 and 3. Furthermore, combination the DG and capacitor gives much better voltage profiles compare to case 4. Ultimately, the combination approach between the NR, DG and capacitor gives better voltage profiles compared to other cases where the voltage at each bus ranging between 0.97 and 1.0 p.u.
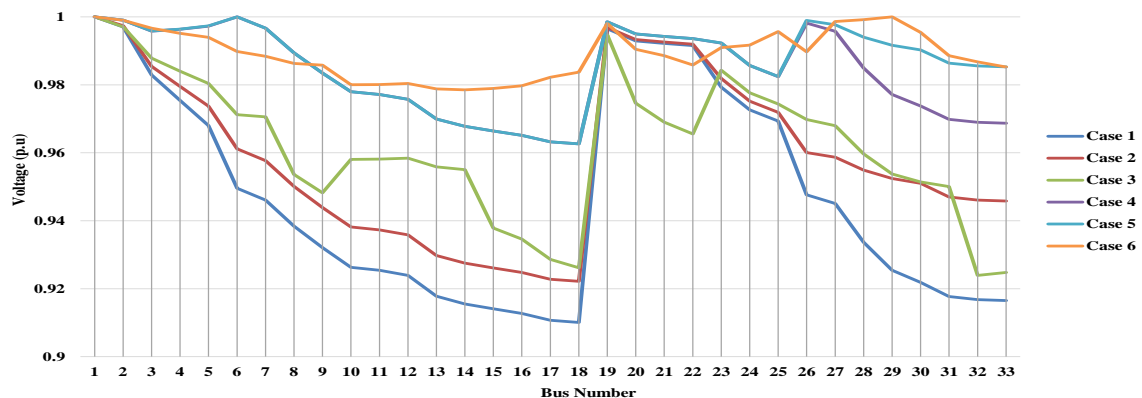

Figure 3. Voltage profiles for all cases

Table 3 shows several comparisons with other methods that published in the literature. From [34] and [35], the location and size for DG and capacitor are pre-determined before performing NR process. Thus, it will lead the solutions trapped in a local minimum. Similarly, in [36], the NR is done first by using minimal spanning tree and after that, the GA will optimize the DG and capacitor based on the pre-determined value of NR. Overall, the proposed approach (Case 6) has shown better reduction in total power loss compared to other references.

Table 3. Comparison with other references

Approach	Total Power Losses (kW)
Proposed (Case 6)	34.90
Minimal Spanning Tree + GA [36]*	78.48
GA [34]**	48
Analytical approach [37]	55.53
GA [35]**	50.15

* Network reconfiguration is determined by using Minimal Spanning Tree, whereas DG and capacitor are determined by using GA

** Location and size for both DG and capacitor are pre-determined.

5. Conclusion

This paper has presented a solution to solve the NR, DG and capacitor, simulataneouly. The coordination for all three approaches is done by using ABC method. The solution is compared with other case studies in term of power loss reduction and voltage profiles. The results showed that combination between NR, DG and capacitor (case 6) gives better results with 82.82% of power loss reduction as well as improvement of voltage profiles. Besides that, comparisons with other references showed promising results in improving the power loss reduction in the test system.

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