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Impact of Distributed Generation Modes in Optimal Coordination Between DG and Capacitor Simultaneously

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***Abstract*—This paper describes the impact of the mode selection in Distributed Generation (DG) has in order to reduce the total power losses in the distribution system when coordination between the DG and capacitor is done simultaneously There are two modes available for the DG to operate which are the Power-Reactive Power (PQ) and Power-Voltage (PV) modes. The coordination between the DG and capacitor is a crucial task that needs to be done during the initial planning stage. Any error in identifying the power output and the location of the DG as well as the size and the location of the capacitor can increase the losses in distribution system. In this paper, some modifications were made on Artificial Bee Colony (ABC) by combining several steps on Artificial Immune System (AIS) will be used. Several cases studies are carried out to see the impact of mode selection on 33-bus distribution system by using MATLAB programming.**

Keywords-*power losses; distributed generation; capacitor placement; meta-heuristic.*

I. INTRODUCTION

One of the aspects that the utilities look during the initial planning stage is total power losses in power system. This matter is important for the utilities in order to obtain more efficient power system. Based on study in [1], 70% of power losses occur in the system is contributed from the distribution network. Moreover, additional cost resulting from uncertainty of price in oil and gas makes reduction of power loss become even more pertinent.

There are many practical solutions have been proposed by the researchers to deal with power loss reduction. One of the popular solutions suggested is by installing a capacitor. Basically, the capacitor works by injecting reactive power on the selected bus in the system to improve the bus voltage, thereby reducing the power loss. Installation of Distributed Generation (DG) at the distribution side is another different approach to solve the problem. With presence of the DG in the system, it will be able to enhance the performance of the system such as improving the voltage, providing index stability and reducing power losses [2].

Despite both of these approaches are proven in reducing the power losses in the distribution system, the solution still does not give the best results. The reason is because the solution is solved separately without considering each other, hence, it will lead the solution to trap in local minimum (meaning not the best solution). Further investigations have been conducted by researchers to find the best solution. Based from the results obtained, they found that by combining the DG and capacitor, this can give better results in term of power losses reduction when compare with separate coordination, i.e. either the DG or the capacitor [3,4,5,6].

The advantages of both of coordination approaches can be utilized if they are carefully calculated. Wrongly determine optimal values can deteriorate the system performance. Several studies have been conducted by the researchers to see the impact of the DGs if they are wrongly coordinated. Based from their findings, improper selection of location and output power of the DGs can increase the power losses even more that the system without DGs [7,8,9]. Hence, suitable method is required to determine the optimal values.

There are various methods that have been published in the research papers to address the problems. Basically, these methods can be categorized into four groups which are analytical, numerical, heuristic and meta-heuristic [10]. Among of these groups, meta-heuristic is favored by the researchers to solve coordination problem due to its simplicity and robustness [10]. Basically, the word meta-heuristic refers to the ability of the algorithm to learn something beyond themselves in searching for optimal solution. Some of examples under meta-heuristic method are Genetic Algorithm (GA), Particle Swarm Optimization (PSO) [11], Artificial Bee Colony (ABC) [12] and Ant Colony Optimization (ACO) [13]. Each of these methods has its own benefits and limitations. Reference [14] has made a thorough discussion on each method. Based on the findings, they concluded that there is no single method that can solve all engineering problems. This problem is known as “no free lunch theorem” [15]. Therefore, some modifications on the method need to done to suit with designated problem.

In this paper, the impact of mode selection of the DG either in Power-Voltage (PV) or Power-Reactive (PQ) during coordination between DG and capacitor is investigated. Since, the problem involved high-dimensional problem, combination of ABC and Artificial Immune System (AIS) optimization is used and tested on 33-bus.

The paper is organized as follows: Section II explains mathematical formulation of optimization method as well as objective function and constraints. Section III briefly discuss on Artificial Immune Bee Colony (AIBC) method. Section IV and V presents results and discussion as well as conclusion of the manuscript.

II. PROBLEM FORMULATION

The aim of the paper is to see the impact of power loss reduction for different modes in DG during coordination between DG and capacitor. Therefore, total power loss is selected as objective function, as presented in (1).

$$\min\ f\left(x_a, x_b, x_c, x_d\right) = \sum_{i=1}^{tl} P_{lineloss,i} \tag{1}$$

where,

x_a	power output of the DG,
x_b	location of the DG,
x_c	size of capacitor,
x_d	location of capacitor,
tl	total number of branches,
$P_{lineloss,i}$	line losses at line i.

To make sure all the parameters are within the boundary, several constraints are imposed in the calculation as shown below:

a) DG power output:

$$DGPO_{\min} \leq DGPO \leq DGPO_{\max} \tag{2}$$

where $DGPO_{max}$ and $DGPO_{min}$ are the minimum and the maximum values of DG power output, respectively.

b) Capacitor size:

In order to have more practical values of capacitor, only several capacitor rating will be selected during the optimization process. The capacity of the capacitor are 300, 600, 900, 1200 and 1500 kVar.

c) Voltage:

$$V_{bus,\min} \leq V_{bus} \leq V_{bus,\max} \tag{3}$$

where $V_{bus,max}$ and $V_{bus,min}$ are the maximum and the minimum permissible voltage at bus, respectively.

d) Total output power of DG:

$$\sum_{k=1}^{dgpowerout\ put} DGPO_k < \sum_{p=1}^{loaddemand} PL_{demand,p} \tag{4}$$

where *dgpowerout* and *loaddemand* are the total power generated by the DG and total load demand on the test system, respectively. Also, $DGPO_{DG}$ is the generated power by the DG based on the optimized value and PL_{demand} is the fix load demand on each bus.

e) Power balance:

$$\sum_{k=1}^{dgpowerout\,put} DGPO_k + P_{utilitygrid} = \sum_{p=1}^{loaddemand} PL_{demand,p} + \sum_{i=1}^{tl} P_{lineloss,i} \tag{5}$$

where $P_{utilitygrid}$ is the power generated by the electric utility.

f) DG Modes:

There are two modes selection available for the DG, either PV or PQ mode. Each of the modes will be selected based on different case studies.

III. AIBC OPTIMIZATION

As previously discussed, coordination between the DG and capacitor involved high-dimensional problem. There are four parameters that need to be optimized which are DG location, DG power output, capacitor location and capacitor size. All of these parameters will be determined by using meta-heuristic optimization. Reference [16] modified the ABC and combined it with AIS where it is known as Artificial Immune Bee Colony (AIBC). The authors used the proposed method to determine optimal coordination between the DG and network reconfiguration.

The ABC was proposed by the Karaboga [12] in 2005. Basically, there are four stages involved in ABC optimization, which are initialization stage, employed bees stage, onlooker bees stage and scout bee stage. All of these stages play important roles to evaluate the best solution. This process similarly follows the behavior of bees in finding the best foods (best solution).

At the first stage (Initialization), the scouts randomly select the food and evaluate the fitness as formulated in (6). During this stage, all the bees automatically changed to employed bees. Based on previous information, the bees will find other new food that are positioned near the previous locations by using (7) and after that calculate new fitness. The comparison between the old and new fitness will be made by using greedy selection, which means only higher value of fitness will be selected by the employed bees.

The information regarding the selected food will be shared with onlooker bees, however, the possibility to be chosen by the bees depends on the amount of nectar as in (8). The processes are repeated until maximum cycle is reached. Meanwhile, if the fitness does not give better results for a set of number (Limit), the bee will ignore the food and ask one bee to explore randomly a new food source.

$$Fitness_i = \frac{1}{1 + OF_i} \tag{6}$$

where $Fitness_i$ is a fitness value and OF_i is an objective function (total power losses).

$$X_{ij}^{new} = X_{ij}^{old} + random[-1,1] \times (X_{ij}^{old} - X_{kj}) \tag{7}$$

where X_{ij}^{new} and X_{ij}^{old} are new and old value of parameter to be optimized (DG location, DG power output, capacitor location and capacitor size). *random* is a value that is produced randomly. X_{kj} is another value of parameter that is selected randomly.

$$probility_i = \frac{Fitness_i}{\sum_{j=1}^{n} Fitness_j} \tag{8}$$

where $probility_i$ is a probability of food i and n is total number of employed bees.

For AIS, there are five processes involved, which are initialization, duplication, mutation, sorting and selection. As previously explained in the ABC process, the new food positioned near the previous food as in (2) are calculated randomly for parameter at each stage. Therefore, with the problem that involved many parameters, the ability of the ABC to search optimal value might be limited.

Some modification have been made in the original ABC by including three processes in the AIS (duplicate, sort and selection) in order to enhance the searching capability of the ABC. This hybridization is known as AIBC. Figure 1 shows basic flow chart of the AIBC process, whereas Table 1 shows comparison of pseudo code for all three optimizations.

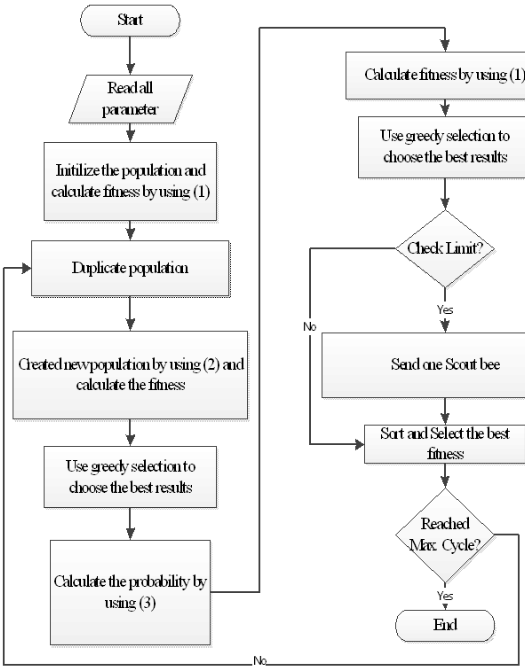

Figure. 1. Basic flow chart of AIBC.

TABLE I. COMPARISON BETWEEN ABC, AIS AND AIBC.

ABC	AIS	AIBC
1) Initialize 2) Employed phase 3) Onlookers phase 4) Check the Limit *if* reached *then* send one scout bees 5) Store best results 6) Check the maximum cycle *if* YES *then* STOP *else* Repeat steps 2 to 6	1) Initialize 2) **Duplicate** 3) Mutation process 4) **Sorting the results** 5) **Select the best results** 6) Check stopping criteria *if* fulfill *then* STOP *else* Repeat steps 2 to 6	1) Initialize 2) **Duplicate** 3) Employed phase 4) Onlookers phase 5) Check the Limit *if* reached *then* send one scout bee *else* 6) **Sorting the results** 7) **Select the best results** 8) Store the best results 9) Check the maximum cycle *if* YES *then* STOP *else* Repeat steps 2 to 9

IV. RESULTS AND DISCUSSIONS

To evaluate the impact of different DG modes during optimal coordination between DG and capacitor, one test system is considered in the analysis. Figure 2 shows the topology for 33-bus systems. The system is connected to 132/12.66 kV substation without any DG and capacitor installed. All the relevant data for the test system can be obtained in [17].

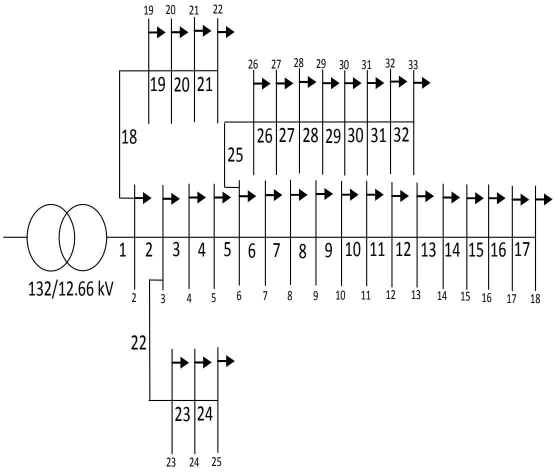

Figure 2. A 33-bus test system.

There are six case studies being considered in the manuscript as tabulated in Table II. Case 1 is considered as the base case to compare with other cases. For Cases 2 and 3, both cases will focus on the coordination of the DG in PQ and PV mode, respectively. The aim for Case 4 is to coordinate the size and the location of the capacitor only. For the last two cases (Cases 5 and 6), the DG and capacitor will be determined simultaneously but with different mode of DG.

TABLE II. VARIOUS CASE STUDIES.

Case	Description
1	Original network without any DG and capacitor installed.
2	Determine optimal output power & location of the DG in PQ mode simultaneously.
3	Determine optimal output power & location of the DG in PV mode simultaneously.
4	Determine optimal size & location of the capacitor.
5	Determine optimal coordination of output power & location of the DG in PQ mode and size & location of capacitor simultaneously.
6	Determine optimal coordination of output power and location of the DG in PV mode and size & location of capacitor simultaneously.

Table III shows comparison of the results for all case studies in term of power losses reduction and optimal values for all parameters. According to the simulation results, it can be clearly seen that coordination between the DG in PV mode with capacitor can give better power loss reduction at about 77.10% from Case 1. Selection of PV mode in DG gives more advantages to the power loss reduction. This can be observed in Cases 2 and 3 where the difference of power loss reduction is 42.82 kW. The same trend can also be seen for Cases 5 and 6 where PV mode gives more power loss reduction. Other observation that can be seen is that all optimal location for all case studies is similar regardless of types of DG modes except the DG power output and capacitor size. Overall, coordination of the DG incorporate with capacitor gives better power loss reduction compare to only one approach (DG coordination or capacitor coordination).

TABLE III. RESULTS FOR ALL CASE STUDIES FOR 33-BUS.

Case	DG output (MW) and location	Capacitor size (MVar) and location	Total power losses (kW)
1	None	none	203.19
2	2.58 (bus 6)	none	104.38
3	2.46 (bus 6)	none	61.56
4	None	1.2 (bus 30)	143.93
5	2.52 (bus 6)	1.2 (bus 30)	52.06
6	2.49 (bus 6)	0.9 (bus 30)	46.53

The voltage profiles for all cases are depicted in Figure 3. It can be observed that from Case 2 until 6, the voltage showed improvement at almost all buses. This is due to the help of capacitor or/and DG improved the voltage at the installed bus as well as near other buses. Overall, combination of the DG in PV mode and capacitor gives better results when compared to other cases.

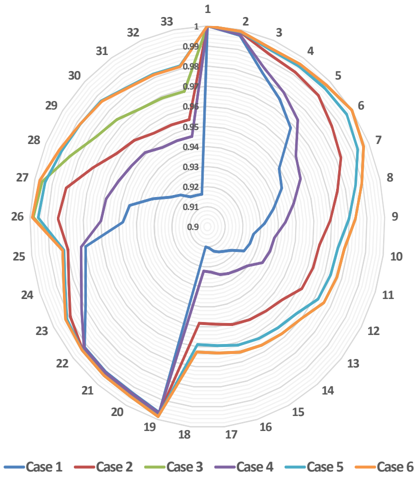

Figure 3. Voltage Profile for all cases.

To shows the effectiveness of the study, comparison of Case 4 with other research works are carried out in term of optimal location and output power of DG, location and size of capacitor as well as total power loss reduction. In order to make a fair comparison, other references are simulated again in PV mode. All the comparisons are tabulated in Table IV. Based the results obtained, it can be observed that Case 4 showed better results in term of power loss reduction.

TABLE IV. COMPARISON WITH OTHER METHODS.

Method	Optimal power output in MW (location)	Optimal capacitor size in MVar (location)	Power losses (kW)
Case 4	2.49 (bus 6)	0.9 (bus 30)	46.53
Bacterial Foraging Algorithm (BFA) [18]	1.25 (bus 12)	0.45 (bus 9)	89.95*
PSO [6]	2.51 (bus 6)	1.46 (bus 30)	52.33*

*The results is simulate again in PV mode

V. CONCLUSION

In this paper, the impact of mode selection for DG during simultaneous coordination between the DG and capacitor is presented. Several case studies are simulated to see the impact of modes selection. The result showed that the optimal location of both DG and capacitor remains the same. However, selection of PV mode in the DG has helped to improve more power loss reduction in the test system. Overall, combination of DG and capacitor has shown better system performance as a whole.

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