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Optimum Placement and Sizing of Battery Storage Systems to Voltage Rise Mitigation in Radial Distribution with Pv Generators

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ABSTRACT

Recently, photovoltaic (PV) power generation has drawn a lot of attention since it is a clean and renewable energy source. However, these PV source may cause the reversal of power flow and leads to the problem of overvoltage. Utilization of battery storage systems (BSS) is an effective way to mitigate the voltage rise problem although their installation cost is high. Thus the optimal location and capacity of BSS are crucial to be known. In this work, enhanced opposition firefly algorithm (EOFA) is employed to obtain the optimal location and capacity of BSS in a radial network. The results show that the installation of BSS at optimal location and capacity can control the voltage rise problem effectively.

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INTRODUCTION

Lately, the use of distributed generation (DG) such as photovoltaic (PV) systems in distribution system has gained a lot of interest from utilities as well as the end users due to the advantages they offer which includes power loss reduction, greenhouse gas reduction, high reliability and etc. However, the installing of PV systems in the network can lead to overvoltage in the grid (Conti, S., *et al.*, 2001). This may cause undesired damages to the users along the grid. To overcome this problem, some methods have been proposed in the literature to mitigate voltage rise problem. Scott *et al.* (2002) suggested a method using load control to regulate the voltage on network with DG. Besides, Varma *et al.* (2009) presented a method where the PV solar farm is used as STATCOM during night time to regulate the grid voltage. Meanwhile, Kakimoto *et al.* (2011) proposed the voltage control of PV generator by combining the series reactor. On the other hand, Cappelle *et al.* (2011) and Kihara *et al.* (2011) have suggested the battery energy storage system (BSS) as a good option in solving the problem of overvoltage. However, installation of BSS at every network bus can be a huge cost to be afforded. In order to solve this problem, the optimal battery location and size should be obtained.

Recently, heuristic optimization methods have gained the popularity among the researchers. They perform better than mathematical optimization techniques in coping with large and complex optimization problems. Vrettos and Papathanassiou (Vrettos, E.I. and S.A. Papathanassiou, 2011) applied GA in optimizing the size of the hybrid system consisting wind turbines, PV and BESS system. Chen *et al.* (2012) also applied GA to calculate the optimal energy storage size by optimizing the investment cost model which is a non-linear objective function. Besides, Bee Colony Optimization was employed to determine the battery size and location for the mitigation of voltage rise caused by PV systems (Chaiyatham, T. and I. Ngamroo, 2012). However, heuristic optimization algorithms always face the problems of being trapped in local optimum and slow convergence rate. In order to overcome these problems, Enhanced Opposition Firefly Algorithm (EOFA), an improved version of Firefly Algorithm (Yang, X., 2008) is proposed in this paper to obtain the optimal location and size of the BSS in a radial distribution network. The studied system and the analysis method will be discussed in the following section.

Analysis Of The Studied System:

The distribution system with integrated PV generation as illustrated in Figure 1 is used in this study (Xiao-yan, X., 2010). The network operates at 380V and consists of M numbers of loads and PV generations. The

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active power of PV and the apparent power for each load are represented as PV_m and $P_m + jQ_m$ respectively where $m=1, 2, 3 \dots M$. The initial bus line voltage, V_0 is set to be constant while the voltage of each customer bus is denoted by V_m . The impedance between customer $m-1$ and customer m is $R_m + jX_m$. The detail system parameters can be obtained in Xiao-yan *et al.* (2010).

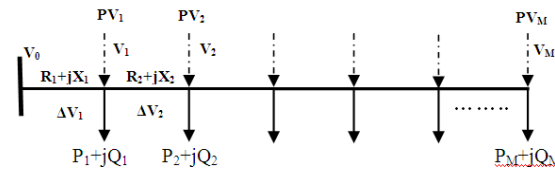


Fig. 1: Radial network with PV.

Objective Function And Algorithm:

The optimal battery size for minimal voltage deviation and power loss in the network can be obtained by minimizing the battery size (BS) as well as the voltage deviation (VD) and power loss (PL). As a result, the objective function can be formulated as shown in Equation 1. The VD is constrained to $380V \pm 10\%$. The optimization is performed by using EOFA.

$$OF = \text{minimize} (BS + VD + PL) \quad (1)$$

Firefly Algorithm:

Firefly Algorithm (FA) was developed by Yang (2008) based on the flashing characteristics of fireflies. Two main issues of FA are the light intensity as well as the attractiveness of the fireflies. The movement of the firefly i when it is attracted by the brighter firefly j is defined by Equation 2.

$$x_i(t) = x_i + \beta_o e^{-\gamma r_{ij}} \left(x_j(t) - x_i(t) \right) + \alpha \left(\text{rand} - \frac{1}{2} \right) \quad (2)$$

where β_o is the attractiveness for $r = 0$, γ is the light absorption coefficient while r is the Cartesian distance between two fireflies, α is the randomization parameter and rand is a random number generator uniformly distributed between zero and one. The procedures for the FA are described as below:

- Step 1: Generate initial population of fireflies randomly.
- Step 2: Evaluate fitness of all fireflies from the objective function (OF).
- Step 3: Update the light intensity (fitness value) of fireflies.
- Step 4: Rank the fireflies and update the position according to their light intensity.
- Step 5: Repeat Step 2 until the optimal result is obtained or the stopping criteria is achieved.

Enhanced Opposition Firefly Algorithm:

The EOFA is the improved FA where inertia-weight function (Yafei, T., 2012) and the opposition theorem (Tizhoosh, H.R. 2005) are used to enhance the performance of the original algorithm. In this work, EOFA is used so that it has great ability to escape from local optimum points and gives better convergence rate.

RESULT AND DISCUSSION

In this study, four case studies are carried out as shown in Table 1. The total power consumption of the loads for all cases is $0.001MW + j0.0001MVar$. For EOFA parameters, population size is set to be 30, number of iteration is set to be 100 while α and γ are set to be 0.9 and 0.01 respectively. The optimization results after 30 runs are shown in Table 2.

Table 1: Types of case study.

Case	PV location	Battery location
1	Bus 1	1, 4 and 8
2	Bus 4	1, 4 and 8
3	Bus 8	1, 4 and 8
4	All bus	1, 4 and 8

From the results, it can be seen that the values for voltage deviation fluctuate the most with different PV and battery location. Some of the values are not acceptable as they deviated more than 10% ($>38V$) from the supplied voltage. Considering all the variable, Bus 8 is found to be the best location for battery placement since it gives relatively small voltage deviation while maintaining similar battery size and power loss are comparable to battery location at Bus 1 and Bus 4.

Table 2: Optimal values for voltage deviation, battery size and power loss after optimization.

PV size (MW)	PV location	Battery location	Voltage Deviation, VD (V)	Battery size (MW)	Power loss (p.u.)
0.1	Bus 1	Bus 1	60.01	0.500	0.0013
		Bus 4	120.14	0.531	0.0045
		Bus 8	9.10	0.558	0.0121
0.1	Bus 4	Bus 1	57.49	0.500	0.0027
		Bus 4	129.56	0.611	0.0021
		Bus 8	2.28	0.605	0.0061
0.1	Bus 8	Bus 1	10.65	0.914	0.0008
		Bus 4	3.25	0.552	0.0003
		Bus 8	16.49	0.525	0.0808
0.1	All bus	Bus 1	224.75	0.501	0.0021
		Bus 4	6.53	0.804	0.0004
		Bus 8	3.05	0.568	0.0035

Conclusion:

This study has presented an application of EOFA in deciding the optimal location and capacity of battery storage systems. The purpose of this study is to mitigate the problem of overvoltage in a PV integrated radial distribution network. The best placement with the minimum required capacity and power loss of battery has obtained. Simulation results show that the battery location at the end of the feeder gives a better control on voltage rise compared to other locations.

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