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Loadability Improvement in Distribution Network using DG Units by Application of Biogeography Based Optimization Algorithm Considering Cable Aging Constraint

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Abstract. Erosion of equipment in power systems mainly cable aging play an important role in reliability of power system, especially in distribution network. Cable aging mostly happens due to metallic structure of power equipment such as cable sheathing erosion. Decreasing reliability of the system and higher risk of failure are some results of cable aging. One of the best way to mitigate the impact of this issue, is reduction of cable current flow by installing Distributed Generations (DGs) in power system. In this paper Biogeography Based Optimization (BBO) algorithm is used to improve voltage profile of the network considering cable aging constraint by optimal siting and sizing of DGs. The IEEE 33-bus standard network is used as the test system and load flow calculations are carried out by Backward/Forward sweep in this work. Three scenarios are investigated and the BBO algorithm is run in 500 iterations for each scenario. The results show the suitability of BBO for this problem in aspect of convergence and finding global optimum value.

Keywords

Cable aging, Loadability, DG, optimal siting and sizing, Biogeography Based Optimization (BBO) algorithm

1. Introduction

Different episodes such as metal structures corrosion and weakening in insulations can lead to equipment aging in distribution system. This harmful aging should be mitigated by both technical ways and maintenance activities. The cost which is needed for maintenance activities to prolong equipment lifetime is the most important reason for its performing limitation, especially at the end stage of equipment life. Therefore, engineers prefer to perform technical ways in order to reduce equipment aging rather than the maintenance activities. In this way, many studies have been done in the literature for reducing the impact of aging in power equipment [1-6].

In [5-6], placement of Distributed Static Compensator (DSTATCOM) has been studied considering cable aging constraint. In [3], optimal placement and sizing of Distributed Generations (DGs) have been performed considering load variations and cable aging constraint. However, in [3], the loadability of the system has not been investigated. In [4], loadability improvement considering cable aging has been studied by optimal placement of DG. However, the optimal size of DG has not been investigated in [4]. In this paper, simultaneous consideration of cable aging and loadability is investigated, by optimal siting and sizing of DGs. Many optimization algorithms have been introduced and applied in the engineering problems [7-12]. In this paper, Biogeography Based Optimization (BBO) algorithm [13] is used to find the optimal sites and sizes of DGs to improve loadability in the distribution network, considering cable aging issues. The proposed method has been applied on IEEE 33-bus test system and suitability of BBO for this problem is shown in the results. In the next Section, the objectives of the paper are formulated. BBO algorithm is expressed in Section III and simulation results of BBO algorithm for the problem is discussed in Section IV. Finally, the paper is concluded in section V.

2. Problem Statement

Cable aging leads to increase in failure probability and so, it should be controlled by maintenance activities. There are two major types for maintenance activity. The first type, known as corrective maintenance, is carried out after a failure and consists of the activities for equipment repairing. The second type, known as preventative maintenance, is done before a failure and consists of the inspection activities. The aim of second part is to prolong the equipment lifetime by slowing the aging process. Predictive and regular strategies are two type for implementing preventive maintenance. In the past 20-25 years, the predictive maintenance, as one of the preventive maintenance approaches, has been studied in the power industry systems. This approach needs assessment process such as calculation, monitoring of situation, modelling etc. On the other hand, regular maintenance approach, which is not interested in the industry, has more cost and need expert engineer but is easy to perform [1].

As shown in Fig. 1, the process of cable aging can be reduced by suitable maintenance activities. However, this facts cannot be fully stopped. As it can be concluded from Fig. 1, one of the suitable maintenance activity to improve cable aging is reduction of its current [3]. If we can decrease the ratio of the current flow to the nominal current in each branches, the process of cable aging will be improved. Therefore, in the proposed Objective Function (OF), if we minimize the ratio of branch currents after to before compensation, the current of branches is reduced and the life of cable is prolonged according to Fig. 1 and Ref. [1]. In the other words, Eq. (1) and Eq. (2) are equal in aspect of cable aging. As discussed in [5-6], by minimization of the following equation cable aging effect is considered in the distribution system:

$$\sum_{i=1}^{N_{branch}} \frac{\text{Current of cable } i \text{ after compensation}}{\text{Current of cable } i \text{ before compensation}} \tag{1}$$

$$\sum_{i=1}^{N_{branch}} \frac{\text{Nominal life of cable } i}{\text{Prolonged life of cable } i \text{ after compensation}} \tag{2}$$

Another term should be added in the OF in order to improve loadability. Finding maximum loadability of the system can be achieved by increasing all the active and reactive loads as follows:

$$P_i = \lambda_i \times P_0 ,\ Q_i = \lambda_i \times Q_0 \tag{3}$$

$$\lambda_i = \lambda_0 + \left(i \times 0.01\right) \quad i = 1, 2, \cdots \tag{4}$$

λ_0 is assumed to 1, in this paper. As shown in Fig. 2, when the voltage collapse is occurred, the achieved λ_i is the latest acceptable λ or maximum loadability (λ_{max}). Therefore, the following OF should be minimized to improve loadability of the system:

$$\text{OF}_{Loadability} = \frac{1/\lambda}{1/\lambda_{max}} \tag{5}$$

Finally, the OF of this paper is as follows:

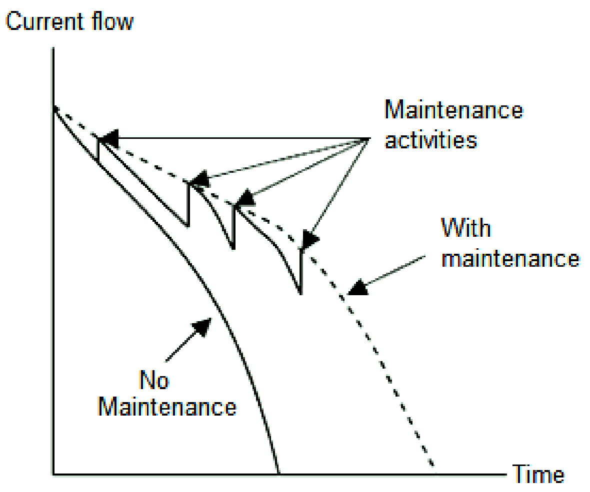

Fig. 1. Relationship between time, preventative maintenance, and current value

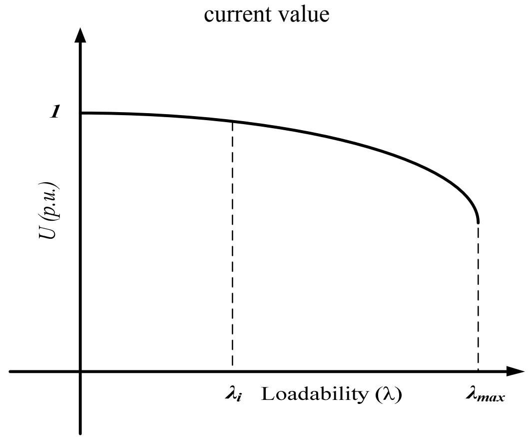

Fig. 2. Voltage-Loadability curve

$$OF = \sum_{i=1}^{N_{branch}} \frac{\text{Nominal life of cable } i}{\text{Prolonged life of cable } i \text{ after compensation}} + \frac{1/\lambda}{1/\lambda_{max}} \tag{6}$$

It should be noted again that in this paper, loadability is $\lambda = 1 + \lambda'$ similar to many previous papers such as [13].

In the next section, BBO will be described.

3. Biogeography Based Optimization Algorithm

BBO is a novel optimization algorithm proposed by Dan Simon in 2008. This algorithm looks at biogeography for its inspiration source. Animals and plants species in a neighboring islands group will migrate over time between the islands for different reasons. Suitability of environmental specifications of some islands for species may lead to gather more species than other islands which have fewer species. The suitability of environmental specifications to absorb species can be quantified by assigning an island suitability index (ISI) to each island. Many specifications of the island may effect on ISI value. After assigning value to each specification, we have the ISI as a function of these values. Each value can be signified by a suitability index variable (SIV). The following formula can show a summary of the mentioned procedure:

$$Island \rightarrow (\, spec_1, \ldots, spec_n \,) \rightarrow (\, SIV_1, \ldots, SIV_n \,) \rightarrow ISI$$

Large ISI for an island represents abundance of species. These species can emigrate to other islands and so, the rate of emigration (μ) and the immigration rate of an island (Ω) is large and small, respectively. It is assumed that ISI and emigration (or immigration) rate has linear relation and are same for all population as shown in Fig. 3.

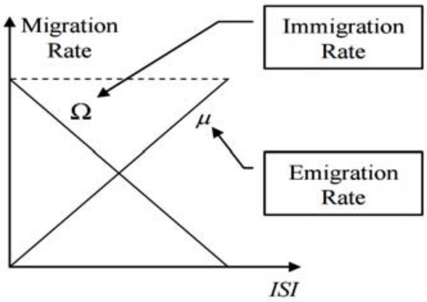

Fig. 3: ISI and island migration rate

A possible solution of a problem can be analyzed as the *n*-tuple (SVI_1, SVI_2,…, SVI_n) companion with the specifications of an island. An island ISI value can be considered as OF value joined with that solution. Determination of the solution as the aim of BBO algorithm can be achieved by maximizing of the ISI over the entire search space. The solution migration rates can be used to share specifications among islands. The decision of immigration of each island specification (SIV) is probabilistically set. Emigrating island is probabilistically chosen using roulette wheel selection normalized by μ, If we decide to immigrate for a SIV. Then, the mutation is probabilistically performed to improve population diversity. A detail formulation of this algorithm is described in [14].

4. Simulation Results

This paper uses an IEEE 33-bus network which is shown in Fig. 7 for simulation studies and its data are given in Appendix 1. MATLAB software as known tool for power system is used to optimize OF in IEEE 33-bus test system. In our simulation studies, we investigates three different scenarios as following:

a) Scenario1: siting and sizing for one DG:

In the first scenario of the studies, site and size of one DG is investigated. The BBO algorithm is run for 500 iterations and the average and minimum values for the OF are shown in Fig. 4. The BBO algorithm, places the DG on bus 17 with the size of 282.7 kVA. As shown in Fig. 4, it can be concluded that the convergence of BBO algorithm is suitable for solving this problem and finding global optimum value. In this scenario the system's maximum loadability is equal to 3.62 ($\lambda = 3.62$ or $\lambda' = 2.62$). Value of loadability indicates that by optimally placement of DG unit using BBO and consideration of cable aging in the OF, system loadability is improved.

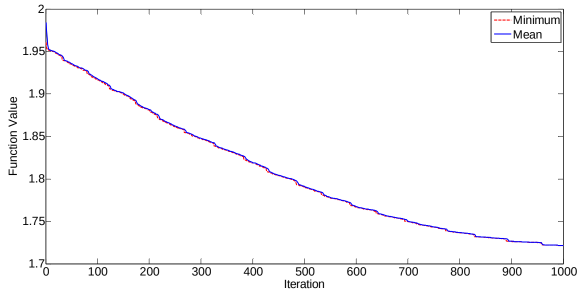

Fig 4. Mean and minimum values of the OF for each iteration in scenario 1

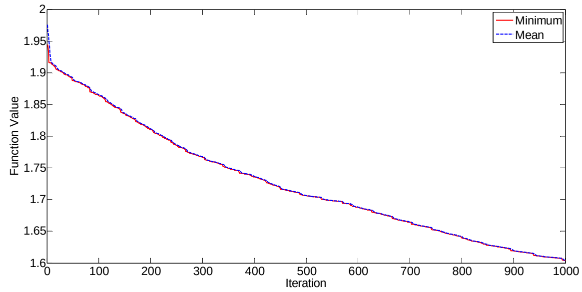

Fig 5. Mean and minimum values of the OF for each iteration in scenario 2

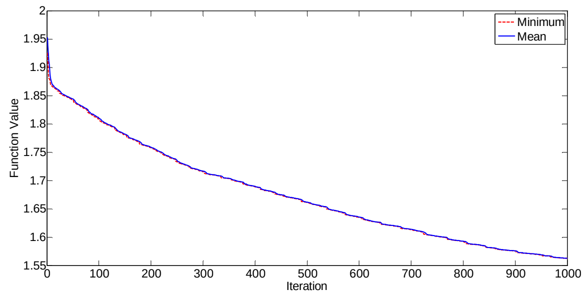

Fig 6. Mean and minimum values of the OF for each iteration in scenario 3

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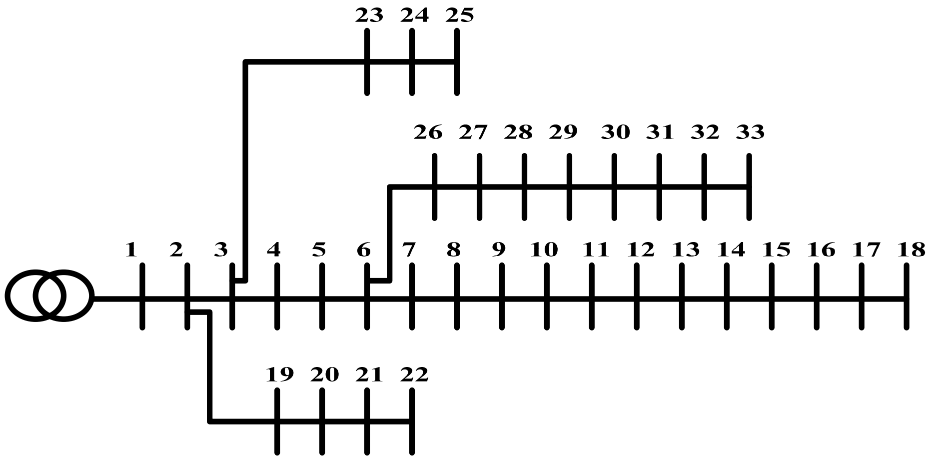

Fig. 7. IEEE 33-Bus test system

b) Scenario2: optimal sites and sizes of two DGs:

In the second scenario, siting two DGs are studied and optimal sites and sizes of them are found during the optimization process which is done by BBO. The result of 500 iterations of BBO algorithm, places the DGs on bus 17 and 14 with the sizes of 240.2 kVA and 228.3 kVA, respectively. The average and minimum values for the OF are shown in Fig. 5 and it can be concluded that the convergence of BBO algorithm is suitable for solving this problem and finding global optimum value. In this scenario the system's maximum loadability is equal to 3.72 ($\lambda = 3.72$ or $\lambda' = 2.72$). Value of loadability in this scenario indicates that by optimally placement of two DG units using BBO and consideration of cable aging in the OF, system loadability is improved.

c) Scenario3: optimal sites and sizes of three DGs:

In the third scenario, we use three DGs to improve voltage profile and cable aging of the system. The average and minimum values resulted from BBO algorithm for the mentioned OF are shown in Fig. 6. As shown in this figure, the suitability of BBO in convergence and finding global optimum value is acceptable in this scenario. BBO algorithm finds bus 13, 14 and 17 as the optimal sites of DGs. The size of them are 195.27 kVA, 186.95 kVA and 199.32 kVA, respectively. In this scenario the system's maximum loadability is equal to 3.76 ($\lambda = 3.76$ or $\lambda' = 2.76$). Value of loadability indicates that by optimally placement of three DG units using BBO and consideration of cable aging in the OF, system loadability is improved.

5. Conclusion

In this paper, voltage profile of a test system is improved considering cable aging constraint. A well-known optimization algorithm namely BBO, is adapted to the problem of IEEE 33-bus network and optimal sites and sizes of DGs are investigated in three different scenarios. As shown in Section IV, the suitability of BBO algorithm on the problem is acceptable in aspects of convergence and finding global optimum value.

Appendix A

IEEE 33-Bus test system data is given in Table A1.

Table A1
IEEE 33-Bus distribution network data

Sending Bus	Receiving Bus	R (Ω)	X (Ω)	Receiving Bus	
				P_L (kW)	Q_L (kVAr)
1	2	0.0922	0.0477	100	60
2	3	0.4930	0.2511	90	40
3	4	0.3660	0.1864	120	80
4	5	0.3811	0.1941	60	30
5	6	0.8190	0.7070	60	20
6	7	0.1872	0.6188	200	100
7	8	1.7114	1.2351	200	100
8	9	1.0300	0.7400	60	20
9	10	1.0400	0.7400	60	20
10	11	0.1966	0.0650	45	30
11	12	0.3744	0.1238	60	35
12	13	1.4680	1.1550	60	35
13	14	0.5416	0.7129	120	80
14	15	0.5910	0.5260	60	10
15	16	0.7463	0.5450	60	20
16	17	1.2890	1.7210	60	20
17	18	0.7320	0.5740	90	40
2	19	0.1640	0.1565	90	40
19	20	1.5042	1.3554	90	40
20	21	0.4095	0.4784	90	40
21	22	0.7089	0.9373	90	40
3	23	0.4512	0.3083	90	50
23	24	0.8980	0.7091	420	200
24	25	0.8960	0.7011	420	200
6	26	0.2030	0.1034	60	25
26	27	0.2842	0.1447	60	25
27	28	1.0590	0.9337	60	20
28	29	0.8042	0.7006	120	70
29	30	0.5075	0.2585	200	600
30	31	0.9744	0.9630	150	70
31	32	0.3105	0.3619	210	100
32	33	0.3410	0.5302	60	40

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