International Conference on Renewable Energies and Power Quality (ICREPQ'16)
Madrid (Spain), 4th to 6th May, 2016
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.14 May 2016

Application of Biogeography Based Optimization Algorithm in Voltage Profile Improvement of Distribution Network by using DSTATCOM Considering Cable Aging Constraint

Seyed-Alireza Ahmadi[1], Hossein Karami[2], Vahid Vahidinasab[1], Gevork B. Gharehpetian[2]

[1] Dept. of Electrical Engineering
Shahid Beheshti University
Tehran, Iran
Emails: se.ahmadi@mail.sbu.ac.ir, v_vahidinasab@sbu.ac.ir

[2] Dept. of Electrical Engineering
Amirkabir University of Technology
Tehran, Iran
Emails: h.karami@aut.ac.ir, grptian@aut.ac.ir

Abstract: In this paper, Biogeography Based Optimization (BBO) algorithm is used to improve voltage profile of the distribution networks considering cable aging constraint and optimal siting and sizing of DSTATCOMs. Recently, researchers show the importance of cable aging effects in the planning of power systems. 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. In order to overcome this issue in power system, one of the best methods is the reduction of cable current flow by installing Flexible Alternating Current Transmission System (FACTS) devices. FACTS devices can help to overcome the hazards that happen in the operation stage of power systems. In this regard, Distributed Static Compensator (DSTATCOM) is used here. The IEEE 33-bus standard network is used in our experimental studies as the test system and load flow calculations are carried out by Backward/Forward sweep method in this work. Three scenarios are investigated in the simulation and the BBO algorithm is used to find optimal sites and sizes for each scenario. The results obtained from BBO, show the privilege of the proposed method.

Keywords

Distribution networks, cable aging, voltage profile, DSTATCOM, optimal siting and sizing, Biogeography Based Optimization (BBO).

1. Introduction

Lifecycle management of equipments attracts a lot of attention in the area of power systems reliability assessment. Equipment aging increases the failure rate of a system and causes unplanned outage of power system. Cable aging as a common type of equipment aging, which happens due to metal structure erosion or weakening in insulation, should be decreased by both technical and maintenance ways. As the maintenance activities for prolonging equipment lifetime is expensive, decision makers in the industry prefer to overcome aging problem by technical ways and not to use maintenance activities as far as possible. Similar to this manuscript, many papers propose attractive technical solutions to mitigate cable aging problem [1-6]. In [4-5], cable aging constraint has been considered in the problem of Distributed Generations (DGs) placement. In [6], optimal placement and sizing of shunt compensators have been performed considering load variations and cable aging constraint. However, in the mentioned studies, voltage profile has not been investigated. In [3], voltage profile improvement considering cable aging has been studied by optimal placement of Distributed Static Compensator (DSTATCOM). However, the optimal size of DSTATCOM has not been investigated in [3]. In this paper, simultaneous consideration of cable aging and voltage profile is investigated, by optimal siting and sizing of DSTATCOMs. 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 DSTATCOMs to improve voltage profile 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 and in

Section III, a brief description about the DSTATCOM in load flow is provided. BBO algorithm is expressed in Section IV and simulation results of BBO algorithm for the problem is discussed in Section V. finally the paper is concluded in section VI.

2. Problem Statement

One of the main hazards that reliability engineers are dealing with in the electric power industry is equipment failure. Cable aging which is a category of equipment aging increases the outage rate of lines in power system. In order to postpone these failures, the maintenance activities are suggested. Fig. 1 shows the popular bathtub curve. From this figure, it can be observed that by using preventive maintenance activities, the useful lifetime of an equipment such as cables can be increased. Despite all of the advantages that maintenance activities have regular maintenance costs a lot and needs expert engineers, so, it is not interested in the industry. As shown in Fig. 1, the process of cable aging can be reduced by suitable maintenance activities. However, this fact cannot be fully stopped. Previously, researchers demonstrate that by reducing the ratio of current flow to the nominal current, a longer lifetime for cables can be expected in the power system. In [5-6], minimization of the following equation proposed to reduce cable aging effect in power networks:

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

By considering the voltage profile of the system in the objective function (OF), the OF can be summarized as follows:

$$OF = \sum_{i=1}^{N_{branch}} \frac{\text{Nominal life of cable } i}{\text{Prolonged life of cable } i \text{ after compensation}} + \sum_{i=1}^{N_{bus}} \left\| V \right| - 1 \right| \quad (2)$$

Both terms of the OF are in p.u. and so we sum them as shown in (2).

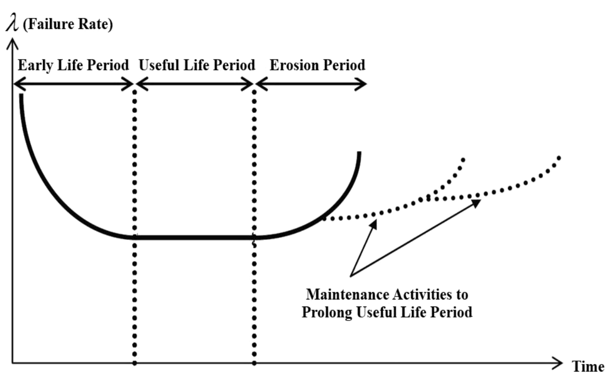

Fig. 1. Bathtub curve; prolonging lifetime of an equipment by using preventative maintenance

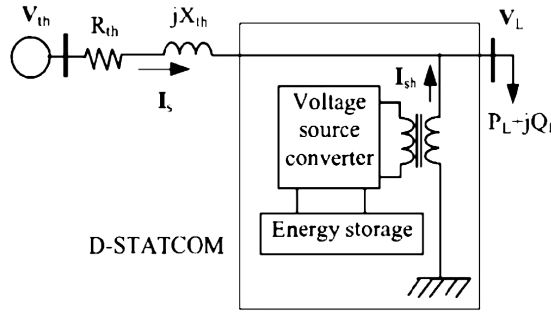

Fig. 2. A typical DSTATCOM diagram.

3. DSTATCOM in Load Flow

DSTATCOM by simultaneous injection and absorption of active and reactive current to the point of common coupling (PCC) connection can lead to proper control of reactive power in the distribution system. The steady state situation of this device, can help to reduce loss of the system and regulate voltage profile. Constant DC voltage is generated in DSTATCOM by using a DC voltage source and it is converted to AC voltage by a voltage source converter (VSC). DSTATCOM is usually connected to the distribution system via a coupling transformer [16]. The DSTATCOM can control power factor and voltage of its bus by setting proper magnitude and phase angle of output current as shown in Fig. 2. Injection or absorption of its current is indicated according to the bus voltage and strategy control of switching.

In this paper, DSTATCOM can only exchange reactive power and similar to many previous works, active power is neglected [17-19]. The model of steady state of DSTATCOM, which is used in this paper, is described in [20]. It should be noted that we use Backward/Forward sweep calculations to perform load flow in this paper.

4. Biogeography Based Optimization Algorithm

BBO is a novel optimization algorithm proposed by Dan Simon in 2008 [13] This algorithm looks at biogeography for its inspiration source. Animals and plants species in a neighboring islands group will migrate over ages between the islands for different reasons. Suitability of environmental specifications in 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

https://doi.org/10.24084/repqj14.415 635 RE&PQJ, No.14, May 2016

of emigration (μ) and the immigration rate of an island (λ) 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.

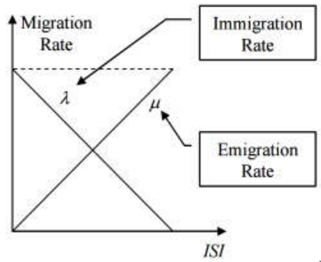

Fig. 3: ISI and island migration rate

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 BOO 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 [13].

5. Simulation Results

In this paper, the IEEE 33-bus network is used for simulation (see Fig. 10). Data of this test system are reported in Appendix 1.

Three different scenarios are investigated here:

Scenario1: siting and sizing for one DSTATCOM:

In the first scenario of the studies, site and size of one DSTATCOM 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 DSTATCOM on bus 17 with the size of 158.17 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. Voltage profile of the system is improved considering cable aging constraint as depicted in Fig. 5. In this paper, the readers can compare the situation of system voltage profile with and without DSTATCOM.

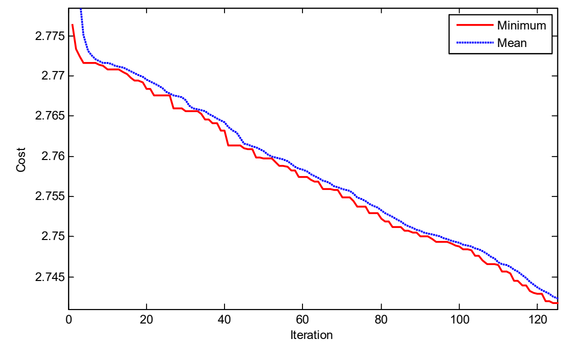

Fig 4. Mean and minimum values of the objective function for each iteration in scenario 1

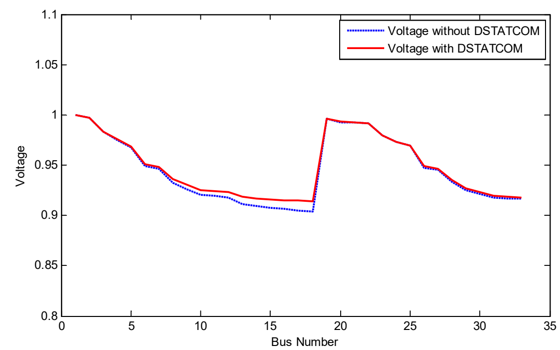

Fig 5. Voltage profiles with or without DSTATCOM in scenario 1

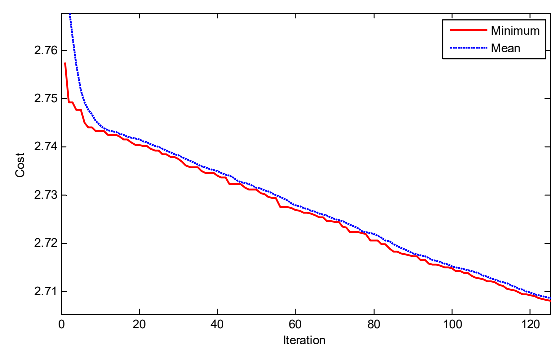

Fig 6. Mean and minimum values of the objective function for each iteration in scenario 2

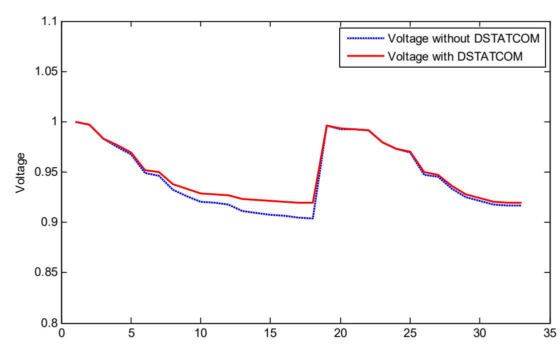

Fig 7. Voltage profiles with or without DSTATCOM in scenario 2

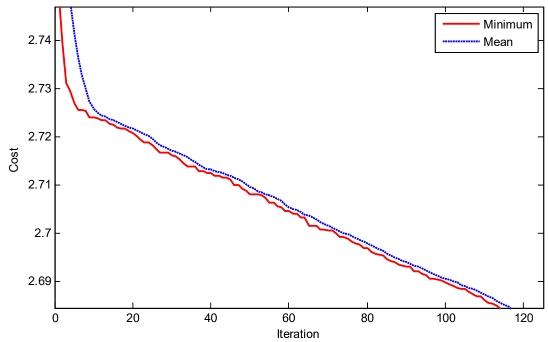

Fig 8. Mean and minimum values of the objective function for each iteration in scenario 3

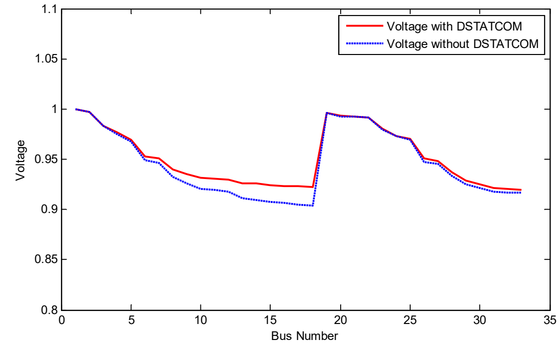

Fig 9. Voltage profiles with or without DSTATCOM in scenario 3

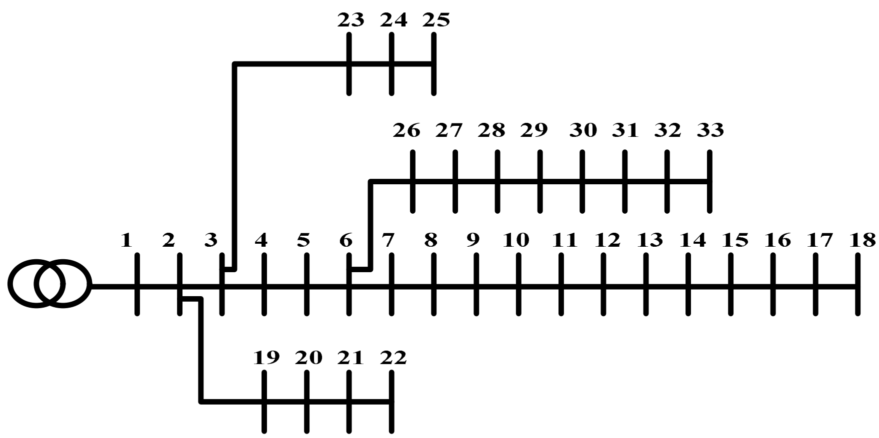

Fig. 10. IEEE 33-Bus test system

a) Scenario2: optimal sites and sizes of two DSTATCOMs:

In the second scenario, siting two DSTATCOMs 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 DSTATCOMs on bus 17 and 14 with the sizes of 138 kVA and 129.76 kVA, respectively. The average and minimum values for the OF are shown in Fig. 6 and it can be concluded that the convergence of BBO algorithm is suitable for solving this problem and finding global optimum value. The figure of system's voltage profile with and without DSTATCOMs for this scenario can be seen from Fig. 7 and it shows obvious voltage profile improvement in the presence of cable aging constraint in the OF.

b) Scenario3: optimal sites and sizes of three DSTATCOMs:

In the third scenario, we use three DSTATCOMs 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. 8. As shown in this figure, the suitability of BBO in convergence and finding global optimum value is acceptable in this scenario. The BBO algorithm finds bus 13, 14 and 17 as the optimal sites of DSTATCOMs with the size of 112.32 kVA, 123.34 kVA and 114.97 kVA, respectively. Fig. 9 demonstrates voltage profile improvement of the system with DSTATCOMs by optimally siting and sizing of DSTATCOMs in the presence cable aging constraint.

6. 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 DSTATCOMs are investigated in three different scenarios. As shown in Section V, 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 are 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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