

Optimal Placement of SVC using Firefly Algorithm

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ABSTRACT

This paper presents an application of Firefly Algorithm (FFA) to recognize the optimal placement of Static Var Compensator (SVC) in a power system network. A circuit model of SVC is utilized to regulate the bus voltage magnitudes and line power flows for improvement of voltage profile and real power loss minimization respectively. The key reason for the voltage instability is the insufficient reactive power at the load buses of the system. Here IEEE 57 bus system is taken into consideration for finding the optimal location and sizing of SVC using FFA. To validate the proposed algorithm, simulation is performed on standard IEEE 57 bus system using MATLAB software package. The simulation results obtained from FFA are compared with Particle Swarm Optimization (PSO) and found to be better.

Keywords: Firefly Algorithm (FFA), Loss Minimization, SVC, Optimal Location, Particle Swarm Optimization (PSO), Voltage Profile.

I. INTRODUCTION

Reactive Power Compensation is a static non-linear programming problem, which optimizes a certain objective function while fulfilling a set of operational, and physical constraints imposed by equipment and equipment limitations [1, 2]. It is also a large-scale static optimization problem with both continuous and discrete decision variables [3]. Several classical optimization techniques such as linear programming, non-linear programming and quadratic programming [4] and the interior point method [5] have been applied to solve the optimal power flow problem. All the above classical optimization have some drawbacks such as getting trapped in local optima or they are suitable for taking into consideration of a explicit fitness function in the optimal power flow problem. These disadvantages can be overcome if meta-

heuristic optimization techniques are utilised to solve the optimal power flow problem. Classical optimization techniques used in optimal power flow problem are based on linear programming and non-linear programming. Fast Quadratic Programming has also been employed for large scale reactive power optimization. The most important disadvantage of these optimization techniques comprises local minima criterion and the time consumption. In order to overcome these shortcomings, meta heuristic optimization algorithms for instance Differential Evolution [6], Ant colony search Algorithm [7], Genetic Algorithm [8], PSO Algorithm and its several modifications such as hybrid PSO [9, 10] were proposed. Recent works on optimal power flow problem includes various meta heuristic optimization techniques like Harmony search Algorithm (HSA) [11] Biogeography-Based optimization (BBO) [12], and

teaching learning based optimization (TLBO) [13] for minimization of real power loss. Dr. Xin-She Yang [14] developed Firefly Algorithm at Cambridge University, which is based on the flashing behaviour of fireflies in 2007. The fitness function of the optimization problem is associated with that of the brightness of firefly and depending on the movement of the fireflies towards the brighter one in the given population thus solving the optimization problem. The rest of this paper is structured as follows. The power flow model of SVC is presented in Sect. 2. The statistical formulation of the optimal power flow problem is presented in Sect. 3. In Sect. 4, firefly algorithm and its performance in reactive power optimization is demonstrated in detail. Simulation results on IEEE 57 bus system and the association with the results provided by particle swarm optimization (PSO) algorithm is shown.

II. POWER FLOW MODEL OF SVC DEVICE

The Static Var Compensator performs similar to a shunt connected variable reactance. SVC either absorbs or generates reactive power so as to control the magnitude of the voltage at the point of connection to the AC network. Fig.1 shows the equivalent circuit of variable susceptance model which is utilized to obtain the SVC non-linear power flow equations and the linearized equations required by the Newton's method. The linearized equation of the SVC device is given by the subsequent equation, where the total susceptance B_{svc} is considered to be the state variable.

$$\begin{bmatrix} \Delta P_i \\ \Delta Q_i \end{bmatrix}^k = \begin{bmatrix} 0 & 0 \\ 0 & \frac{\partial Q_i}{\partial B_{svc}} \end{bmatrix}^k \begin{bmatrix} \Delta \theta \\ \Delta B_{svc} \end{bmatrix}^k \quad (1)$$

The variable shunt susceptance, B_{svc} is modified at the ending of every iteration (k),

$$B_{svc}^{k+1} = B_{svc}^k + \Delta B_{svc}^k \quad (2)$$

Reactive power drawn by SVC device, which is also reactive power injected, Q_{svc} at bus i , is

$$Q_{svc} = Q_i = -V_i^2 B_{svc} \quad (3)$$

The current drawn by SVC depending on the equivalent circuit of SVC is

$$I_{svc} = jB_{svc} V_i \quad (4)$$

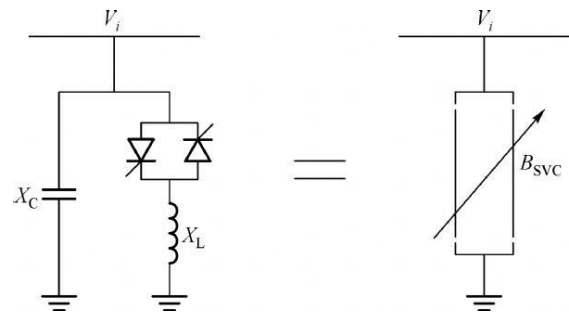


Figure 1. Model of SVC

III. FORMULATION OF REACTIVE OPTIMIZATION PROBLEM

The FACTS devices are to be installed at suitable positions with best possible parameters that curtail the real power loss for better deployment of the existing power system. This paper aims to build up a strategy that executes optimal placement of SVC with an intention of curtailing active power loss and enhancing voltage profile.

A. Formulation of Objective Function

The goal of using FFA is to curtail active power loss, which can be calculated from the load flow solution [14], and described as

$$\text{Min } P_{\text{loss}} = \sum_{l=1}^{nl} G_l (V_{i2} + V_{j2} - 2V_i V_j \cos \delta_{ij}) \quad (5)$$

B. Operating Constraints for the Optimal Placement Problem

The optimal power flow problem is subject to the subsequent equality and inequality constraints

(i) Power flow Constraints

$$P_i = V_i \sum_{j=1}^N V_j (G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij}) = 0 \quad (6)$$

$$Q_i = V_i \sum_{j=1}^N V_j (G_{ij} \sin \theta_{ij} + B_{ij} \cos \theta_{ij}) = 0 \quad (7)$$

Where 'i' and 'j' are buses and N is number of buses

(ii) Operating limits of the voltage

$$V_{\min} \leq V_i \leq V_{\max} \quad (8)$$

(iii) Reactive Power Generation Limit

$$Q_{\min} \leq Q_{Gi} \leq Q_{\max} \quad (9)$$

(iv) SVC size limit

$$-200 \text{MVAR} \leq Q_{\text{SVC}} \leq 200 \text{MVAR} \quad (10)$$

IV. FIREFLY ALGORITHM

The firefly algorithm is a nature inspired swarm intelligence technique, enthused by the sporadic activities of fireflies. It is analogous to other meta-heuristic optimization algorithms utilizing swarm intelligence for instance PSO. The main intention for a firefly's flash is to function as a indication structure to exert a pull on other fireflies. The intensity (I) of flashes diminishes as the distance (r) augments and thus the majority of the fireflies can correspond barely up to quite a few hundred meters.

The Firefly Algorithm was based on the subsequent idealized activities of the flashing features of fireflies:

1. All fireflies are unisexual, so that one firefly will be engrossed to all other fireflies;
2. The degree of attractiveness depends on their brightness, and for any two fireflies, the firefly with lesser brightness will be engrossed

by the firefly with higher brightness; on the other hand, the brightness can reduce as their distance increases.

3. It will move indiscriminately if there are no fireflies brighter than a given firefly.

The pseudo code of the FFA can be formulated depending on these three idealized conventions.

Pseudo Code of the Firefly Algorithm:

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Define Objective function
Generate initial population of fireflies;
Define light intensity;
Describe absorption coefficient  $\gamma$ ;
While (TG < Max No. of Generations)
  For r = 1 to n (all n fireflies);
    For s=1 to n (all n fireflies)
      If ( $I_r > I_s$ ), move firefly i towards j;
    End if
  Determine new solutions and update the
  value of light intensity;
End for s;
End for r;
Rank the fireflies and find the current best;
End while;
Post process results and visualization;
End procedure;

```

The brightness of the firefly is found out by the fitness function. FFA has two major advantages over other optimization techniques: ability of dealing with multimodality and the automatic subdivision. Initially, FFA depends on attraction and attractiveness decreases with distance. Secondly, this subdivision permits the fireflies to be capable of finding all optima concurrently if the size of the population is adequately superior to the number of modes. FFA primarily creates a swarm of fireflies positioned arbitrarily in the search space. Preliminary allocation is generally formed from a standardized indiscriminate allocation and the location of each firefly in the search space exemplifies a probable solution of the optimization problem.

V. SIMULATION RESULTS

The Firefly Algorithm has been applied to determine the suitable location of the FACTS device for IEEE 57-bus system using MATLAB software. Simulation results obtained are compared with PSO. The standard IEEE 57-bus system has 41 transmission lines and six generator buses (Bus No 2, 3, 6, 8, 9 and 12). Table 1 shows the application results in terms of the position and size of the SVC device and the ensuing transmission losses. For the appropriate position and size of FACTS device, the reactive power generation is lesser in FFA method when compared to PSO. Table II shows the voltage profile under different load conditions determined using FFA and

PSO and it is observed that there is an improvement of voltage profile of the system after reactive power compensation by means of Firefly Algorithm. The system load was increased gradually from the base case for this purpose. The system was loaded from its base case up to load factor (L.F) of 1.4 in FFA and PSO. The total active and reactive power losses, total active and reactive power generation of the system, reactive power generation of each generator, size and bus position of SVC device are presented in Table I. In FFA algorithm, the reactive power generation is lesser than the PSO algorithm for the appropriate size and location of FACTS device. The transmission line losses in FFA method are relatively lesser than the PSO method.

TABLE I. Reactive Power Optimization Results Under Different Load Conditioned In FFA & PSA Algorithm

	L.F	Q_{g2} (MV AR)	Q_{g3} (MVA R)	Q_{g6} (MVA R)	Q_{g8} (MV AR)	Q_{g9} (MV AR)	Q_{g12} (MVA R)	Q_{gT} (MVA R)	Q_{Tloss} (MVA R)	P_{gT} (MW)	P_{Tloss} (MW)	Size of SVC (MVA)	Location (Bus No)
FFA	1	0.891	-0.97	10.124	72.75	-	145.89	345.81	158.78	1224.69	24.69	43.676	7
	1.1	8.342	-0.679	-6.783	64.85	2.014	124.73	365.91	181.46	1231.46	28.036	99.352	12
	1.2	9.147	43.568	20.136	80.14	-	152.47	487.48	287.10	1262.76	62.368	129.458	16
PSO [15]x	1	0.775	-0.47	4.369	63.52	-	121.58	324.78	155.83	1223.56	27.76	52.374	9
	1.1	7.437	-0.445	-3.301	50.14	1.854	110.56	341.41	177.90	1226.94	31.142	115.785	15
	1.2	7.132	39.175	12.047	77.47	-	136.71	463.01	283.02	1260.80	65.006	150.766	15

TABLE II. Voltage Profile at Different Buses in FFA and PSO Algorithm under Different Load Conditions

Bus No	L.F = 1		L.F = 1.1		L.F = 1.2	
	PSO[15]	FFA	PSO[15]	FFA	PSO[15]	FFA
1	1.04	1.04	1.04	1.04	1.04	1.04
2	1.01	1.01	1.01	1.009	1.01	1.01
3	0.985	0.984	0.985	0.983	0.985	0.978
4	0.9786	0.9775	0.9785	0.9767	0.976	0.965
5	0.9758	0.9747	0.9756	0.9732	0.973	0.969
6	0.98	0.977	0.98	0.979	0.98	0.976
7	0.9832	0.9830	0.992	0.990	0.992	0.984
8	1.005	1.003	1.005	1.002	1.005	1.002
9	0.98	0.975	0.98	0.978	0.97	0.965
10	0.988	0.976	0.9886	0.9868	0.97	0.959
11	0.9771	0.9761	0.9772	0.9765	0.962	0.955
12	1.015	1.0132	1.015	1.009	0.995	0.984
13	0.9821	0.9813	0.9837	0.9821	0.967	0.948
14	0.9748	0.9722	0.9774	0.9769	0.962	0.958
15	0.9909	0.9901	0.9924	0.9913	0.982	0.971
16	1.0134	1.0124	1.0126	1.0124	0.99	0.987
17	1.0175	1.0165	1.0163	1.0159	0.999	0.995
18	0.9777	0.9697	0.9776	0.9765	0.972	0.969
19	0.9612	0.9572	0.9694	0.9679	0.957	0.949

20	0.9639	0.9628	0.9777	0.9759	0.965	0.958
21	1.0227	1.0216	1.0487	1.0468	1.038	1.027
22	1.0263	1.0234	1.0538	1.0527	1.043	1.039
23	1.0242	1.0145	1.0583	1.0546	1.049	1.038
24	1.0045	1.0021	1.1507	1.1490	1.173	1.168
25	0.9713	0.9697	1.0824	1.0817	1.091	1.087
26	0.9632	0.9642	1.0906	1.0870	1.11	1.105
27	0.9816	0.9743	1.0428	1.0411	1.049	1.037
28	0.9951	0.9871	1.0324	1.0317	1.035	1.029
29	1.0076	1.0069	1.0309	1.0299	1.0318	1.0295
30	0.9579	0.9567	1.0583	1.0578	1.0623	1.0591
31	0.9475	0.9469	1.0199	1.0178	1.014	1.009
32	0.9857	0.9843	1.0141	1.0125	1.0021	1.0017
33	0.9835	0.9829	1.0119	1.0112	0.9995	0.9981
34	1.0217	1.0203	0.9964	0.9958	0.9752	0.9749
35	1.031	1.029	1.0014	1.0009	0.9808	0.9799
36	1.0264	1.0259	1.0098	1.0089	0.9905	0.9894
37	1.0265	1.0234	1.0184	1.0175	1.0006	1.0039
38	1.0311	1.0294	1.0464	1.0435	1.0331	1.0289
39	1.0241	1.0235	1.016	1.0156	0.9976	0.9864
40	1.0226	1.0216	1.0061	1.0049	0.9863	0.9755
41	1.0117	1.0127	1.0053	1.0028	0.9865	0.9814
42	0.9879	0.9866	0.9792	0.9763	0.9553	0.9497
43	1.0161	1.0129	1.0143	1.0129	0.998	0.993
44	1.032	1.029	1.0442	1.0439	1.0315	1.0295
45	1.0446	1.0435	1.051	1.047	1.0432	1.0387
46	1.0691	1.0595	1.0753	1.0689	1.0613	1.0598
47	1.0465	1.0395	1.0561	1.0514	1.0416	1.0399
48	1.0418	1.0438	1.053	1.049	1.0384	1.0376
49	1.0478	1.0469	1.0558	1.0539	1.0389	1.0358
50	1.032	1.029	1.0367	1.0323	1.0151	1.0124
51	1.0555	1.0499	1.0568	1.0557	1.036	1.028
52	0.9703	0.9692	0.9871	0.9852	0.9779	0.9758
53	0.9569	0.9487	0.9704	0.9691	0.9569	0.9553
54	0.9879	0.9797	0.9952	0.9940	0.9824	0.9793
55	1.0279	1.0236	1.0295	1.0278	1.0193	1.0175
56	0.9938	0.9925	0.9843	0.9839	0.9608	0.9597
57	0.9932	0.9879	0.9833	0.9829	0.9595	0.9573

VI. CONCLUSION

In this paper firefly algorithm has been applied to recognize the best possible locations of SVC device and their parameter with the purpose of minimizing the voltage deviations to improve the load bus voltage profile. Application results reveal that the recognized size and location of SVC device reduce the network real power loss. It is feasible that with the application of firefly algorithm can result in the minimization of the active power losses and proper implementation of power system planning and operation.

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