RESEARCH ARTICLE OPEN ACCESS

Optimal Location of Static Var Compensator Using Bat Algorithm for the Improvement of Voltage Profile

D. Venugopal*, Dr. A. Jayalaxmi**
*(Associate Professor, Electrical and Electronics Engineering Department, Kamala Institute of Technology and Science, Singapur ,Karimnagar, Telangana State, India)
**(Professor, Electrical and Electronics Engineering Department, Jawaharlal Nehru Technological University College of Engineering, Kukatpally, Hyderabad, Telangana State, India)

ABSTRACT

This paper proposes optimal location of FACTS devices in power system using Evolutionary algorithms. The location of FACTS controllers, their type and rated values are optimized simultaneously by using the proposed algorithm. From the FACTS devices family, shunt device Static Var Compensator (SVC) is considered. The proposed BAT algorithm is a very effective method for the optimal choice and placement of SVC device to improve the Voltage profile of power systems. The proposed algorithm has been applied to IEEE 30 bus system.

Keywords–Flexible AC Transmission System, Static Var Compensator, Voltage Stability.

I. INTRODUCTION

In recent years, with increasing development of power grids, the economic aspects of a power system are more considered. Because of deregulation and restructuring of the power markets use of Flexible AC Transmission System (FACTS) devices are inevitable. The maximum capability of power systems can be exploited by means of FACTS devices. Nowadays, development of power electronic devices cause reduction in the cost of FACTS devices and therefore application of FACTS devices especially in distribution networks is more viable. Because of the economical considerations, installation of FACTS Controller in all of the buses or lines is impossible and unnecessary. There are numerous methods for finding optimal locations of FACTS devices in power systems [2-3].

The secure operation of power system has become an important and critical issue in today's large, complex and load increasing system. Security constraints such as thermal limits of transmission lines and bus voltage limits must be satisfied under all system operational conditions. FACTS devices can reduce the flow of heavily loaded lines, maintain the bus voltage at desired levels and improve the stability of the power network. It is important to ascertain the location for placement of these devices because of their considerable costs. By controlling the power flows in the network without generation rescheduling or topological changes FACTS devices can improve the performance considerably [4-6]. The insertion of such devices in electrical systems seems to be a promising strategy to decrease the transmission congestion and to increase available transfer capability. Using controllable components such as series capacitor line flows can be changed in such a way that thermal limits are not violated, losses minimized, stability margins increased, contractual requirement fulfilled etc., without violating specific power dispatch.

The increased interest in these devices is essential due to two reasons. Firstly, the recent development in high power electronics has made these devices cost effective [7] and secondly, increased loading of power systems, combined with deregulation of power industry, motivates the use of power flow control as a very cost effective means of dispatching specified power transactions.

In the proposed work, first the locations of the FACTS devices are identified by calculating different line flows. Voltage magnitude and the phase angle of the sending end buses of the lines where major active power flow takes place are controlled by UPFC. TCSC's are placed in the lines where reactive power flows are very high and the SVC's are connected at the receiving end buses of the other lines where major reactive power take place. A BAT Algorithm based approach considering the effect of the shunt type of FACTS device is presented and the effectiveness of this technique is clearly evident from the results.

This paper proposes a new BAT based algorithm for optimal placement and sizing of SVC unit. Simulations are performed to investigate the impact of SVC of the IEEE-30 bus system. The Proposed method shows the benefits of SVC in a deregulated power market and demonstrates how it may be utilized by ISO to prevent congestion.

II. STATIC MODELING OF FACTS CONTROLLERS

This section focuses on the modeling of FACTS devices, namely SVC [14]. The power flows of the line connected between bus-i and bus-j having series impedance $r_{ij} + jx_{ij} \left(= {}^{1}/_{(g_{ij} + jb_{ij})} \right)$ and without any FACTS controllers [1], can be written as,

$$P_{ij} = V_i^2 g_{ij} - V_i V_j \left(g_{ij} \cos \delta_{ij} + b_{ij} \sin \delta_{ij} \right) \quad \text{-----(1)}$$

$$Q_{ij} = -V_i^2 \left(b_{ij} + B_{sh} \right) - V_i V_j \left(g_{ij} \sin \delta_{ij} - b_{ij} \cos \delta_{ij} \right) \quad \text{-----(2)}$$

(2)where V_i, V_j, δ_{ij} are the voltage magnitudes at bus-i and bus-j and the voltage angle difference between bus-i and bus-j is given by

$$g_{ij} = \frac{r_{ij}}{r_{ij}^2 + x_{ij}^2} \quad , \quad b_{ij} = \frac{-x_{ij}}{r_{ij}^2 + x_{ij}^2}$$

Similarly, the real power $\left(P_{ji} \right)$ and reactive power $\left(Q_{ji} \right)$ flows from bus-j to bus-i in the line can be written as

$$P_{ji} = V_j^2 g_{ij} - V_i V_j \left(g_{ij} \cos \delta_{ij} - b_{ij} \sin \delta_{ij} \right) \quad (3)$$

$$Q_{ji} = -V_j^2 \left(b_{ij} + B_{sh} \right) + V_i V_j \left(g_{ij} \sin \delta_{ij} + b_{ij} \cos \delta_{ij} \right) \quad (4)$$

2.1 Static representation of SVC

SVC is a shunt connected static Var generator or consumer whose output is adjusted to exchange capacitive or inductive Var so as to maintain or control specific parameters of electrical power system, typically bus voltage [10,11]. Like the TCSC, the SVC combines a series capacitor bank shunted by thyristor controlled reactor. Figure 1(a) shows SVC structure and fig.1(b). Shows SVC represented as a continuous variable shunt susceptance.

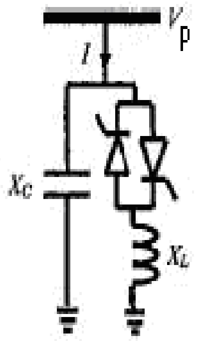

Figure 1(a)
SVC structure

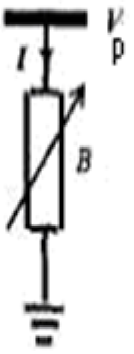

Figure 1(b)
SVC as variable shunt susceptance

The SVC load flow models can be developed treating SVC susceptance as control variable. Assuming that SVC is connected at node-p to maintain the bus voltage at V_p, the reactive power injected by the controller is given by (5).

$$Q_{pSVC} = -V_p^2 B_{pSVC} \quad (5)$$

The linearized load flow model makes use of eqn. (5) to modify the corresponding Jacobian elements at SVC bus. The SVC load flow model can be developed treating SVC susceptance as control variable (B_{SVC}).

III. Population generation

The goal of the present optimization is to find the best location of a given number of FACTS devices in accordance with a defined objective function within the equality and inequality constraints [14]. The configuration of FACTS devices is encoded by three parameters: the location, type and its rating. Each individual is represented by n_{FAC}number of strings, where $n_{FAC}$is the number of FACTS devices to be optimally located in the power system [3], as shown in figure.

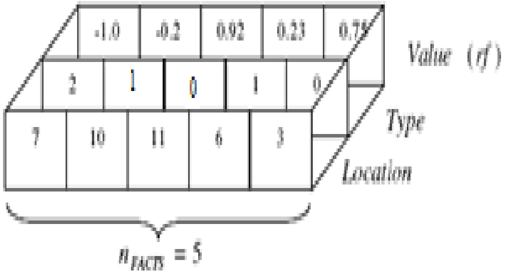

Figure 2.Individual configuration of FACTS devices

The first value of each string corresponds to the location information. It must be ensured that on one transmission line there is only one FACTS device.The second value represents the type of FACTS device (n_{ty_1}used the values assigned to FACTS devices are: "1" for SVC located at a bus, "0" for no FACTS device. The last value *rf* represents the rating of each FACTS device. This value varies continuously between –1 and +1. If the selected FACTS device is SVC, then the rated value is SVC susceptance (Bsvc) and this value is generated between -0.45 p.u to +0.45 p.u.

To obtain population size of Bat Algorithm, the above operations are repeated n_{Ind} times, where n_{Ind} is number of individuals of the population. The objective function is computed for every individual of the particle and assigned fitness. In this paper, the objective function is defined in order to quantify the impact of the FACTS devices on the state of the power system and is presented in the next section.

IV. Objectives of the Optimization

The objective considered here is the Voltage Stability (VS) maximization.

4.1 Voltage Stability (VS) maximization

The objective function concerns about voltage levels. It favors buses voltages close to 1 p.u. The function is calculated for all buses of the power system. For voltage levels comprised between 0.95 p.u. and 1.05 p.u., the value of the objective function

VS is equal to 1. Outside this range, the value decreases exponentially with the voltage deviation [14].

$$VS = \prod_{BUS} J_2 \qquad (6)$$

$$J_2 = \begin{cases} 1 & ; if\ 1.05 \geq V_b \geq 0.95 \\ e^{[\mu(1-V_b)]} & ; \quad \text{otherwise} \end{cases}$$

where, V_b is Voltage at bus b and μ is a small positive constant equal to 0.1.

In most of the optimization problems, the constraints are considered by using penalty terms in the objective function. In this paper also, the objective function used, penalizes the configurations of FACTS devices which cause over or under voltages at buses [3]. The bus voltages are penalized, if bus voltage levels do not lie between 0.95 and 1.05 p.u.

V. Bat algorithm

BAT Algorithm is an optimization algorithm based on the echolocation behavior of bats. The capability of echolocation of bats is fascinating as these bats can find their prey and discriminate different types of insects even in complete darkness [17]. The advanced capability of echolocation of bats has been used to solve different optimization problems. Echolocation of bats works as a type of sonar in bats, emits a loud and short pulse of sound, wait as it hits into an object, the echo returns back to their ears. Thus, bats can compute how far they are from an object. In addition, this amazing orientation mechanism makes bats being able to distinguish the difference between an obstacle and a prey, allowing them to hunt even in complete darkness. Based on the behavior of the bats, Yang has developed a new and interesting metaheuristic optimization technique called BAT Algorithm. Such technique has been developed to behave as a band of bats tracking prey/foods using their capability of echolocation.

5.1 Bat Algorithm idealized rules.

1. All bats use echolocation to sense distance, and they also know the difference between food/prey and background barriers in some magical way.
2. Bats fly randomly with velocity V_i position X_i with a fixed frequency f_{min} (or wavelength λ),varying wavelength λ (or frequency f) and loudness A_o to search for prey. They can automatically adjust the wavelength (or frequency) of their emitted pulses and adjust the rate of pulse emission r€[0,1] depending on the proximity of their targets.
3. Although the loudness can vary in many ways, we assume that the loudness varies from a large (positive) A_o to a minimum value A_{min}.
4. In simulations, we use the virtual bats naturally, we have to define the rules how their positions X_i and velocities V_i in a d-dimensional search space are updated.

The new positions X_i and velocities V_i in a dimensional search space are updated using the following equations. The new solutions X_i^t and velocities V_i^t at time step t are given as,

$$f_i = f_{min} + (f_{max} - f_{min})\beta \qquad (7)$$

$$V_i^t = V_i^{t-1} + (X_i^t - X_o) f_i \qquad (8)$$

$$X_i^t = X_i^{t-1} + V_i^t \qquad (9)$$

Where βϵ [0,1] is a random vector drawn from a uniform distribution. Here X_o is the current global best location (solution) which is located after comparing all the solutions among all the n bats. As the product $\lambda_i f_i$ is the velocity increment, we can use either f_i(or λ_i) to adjust the velocity change while fixing the other factor λ_i(or f_i), depending on the type of the problem of interest. Initially each bat is randomly assigned a frequency which is drawn uniformly from $[f_{min}, f_{max}]$. For the local search part, once a solution is selected among the current best solutions, a new solution for each bat is generated locally using random walk.

$$X_{new} = X_{old} + \epsilon A^t \qquad (10)$$

Where ϵ€ [-1,1] is a random number, while $A^t = \langle A_i^t \rangle$ is the average loudness of all the bats at this time step. The flowchart of the generalized Bat algorithm is shown in Figure 3.

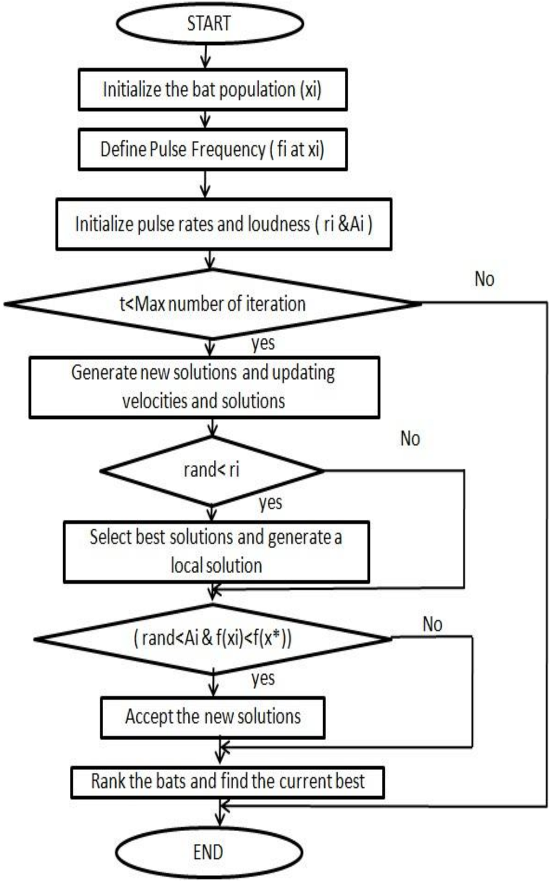

Figure 3: Flow Chart of the generalized BAT Algorithm

VI. SIMULATION RESULTS

In this paper traditional fast decoupled load flow method is applied to find the load flow analysis, which is done using MATLAB.This is considered as the base case. IEEE 30 Bus test system is considered which consists of 3 generators and 3 synchronous condensers and 24 PQ Buses (or load bus). The problem to be addressed consists of finding the optimal location (Bus Number) and corresponding rating / sizing of FACTS Devices (Power rating of SVC and Reactance value of TCSC).Excluding the slack bus, the selection process is performed among 40 line configurations/combinations. The purpose of optimization technique is to identify the effective location and determine the sizing of the corresponding FACTS device (SVC), using BAT algorithm.

Fast Decoupled Load flow analysis of IEEE-30 bus system is tabulated in Table1.The results for individual device (SVC) Performance for the test case IEEE-30 bus system is tabulated in the Table 2. The optimal sizing and location of proposed FACTS device performance has shown in figure4

Table1: Load Flow Analysis for IEEE-30 Bus System for Base Case

V(p.u)	Angle(δ)	P(MW)	Q(MVAR)
1.06	0	260.928	-17.118
1.043	-5.3474	18.3	35.066
1.0217	-7.5448	-2.4	-1.2
1.0219	-9.2989	-7.6	-1.6
1.01	-14.1542	-94.2	16.965
1.0121	-11.088	0	0
1.0035	-12.8734	-22.8	-10.9
1.01	-11.8039	-30	0.691
1.0507	-14.1363	0	0
1.0438	-15.7341	-5.8	17
1.082	-14.1363	0	16.27
1.0576	-14.9416	-11.2	-7.5
1.071	-14.9416	0	10.247
1.0429	-15.8244	-6.2	-1.6
1.0384	-15.9101	-8.2	-2.5
1.0445	-15.5487	-3.5	-1.8
1.0387	-15.8856	-9	-5.8
1.0282	-16.5425	-3.2	-0.9
1.0252	-16.7273	-9.5	-3.4
1.0291	-16.5363	-2.2	-0.7
1.0293	-16.2462	-17.5	-11.2
1.0353	-16.0738	0	0
1.0291	-16.2528	-3.2	-1.6
1.0237	-16.4409	-8.7	-2.4
1.0202	-16.0539	0	0
1.0025	-16.4712	-3.5	-2.3
1.0265	-15.5558	0	0
1.0109	-11.7436	0	0
1.0067	-16.7777	-2.4	-0.9
0.9953	-17.6546	-10.6	-1.9

Table 2: Load Flow Analysis using Fast Decoupled Load Flow method with SVC for IEEE-30 Bus system using BAT Algorithm

SVC for IEEE-30 Bus System			
BAT Algorithm			
V(p.u)	Angle(δ)	P(MW)	Q(MVAR)
1.06	0	261.0081	-19.9262
1.045	-5.3758	18.3	52.0155
1.0204	-7.5393	-2.4	-1.2
1.0113	-9.2873	-7.6	-1.6
0.9957	-14.0098	-94.2	3.0782
1.0092	-11.0661	0	0
0.9981	-12.8114	-22.8	-10.9
1.01	-12.1625	-30	17.1577
1.0503	-14.3566	0	0
1.0446	-15.9701	-5.8	-2
1.082	-14.1153	0	17.348
1.0568	-14.9656	-11.2	-7.5
1.071	-14.9656	0	10.8723
1.0419	-15.8472	-6.2	-1.6
1.0373	-15.9312	-8.2	-2.5
1.044	-15.5578	-3.5	-1.8
1.0395	-15.9718	-9	-5.8
1.0277	-16.5528	-3.2	-0.9
1.0291	-16.7254	-9.5	-3.4
1.0292	-16.5283	-2.2	-0.7
1.0321	-16.1508	-17.5	-11.2
1.0327	-16.3967	0	0
1.02684	-16.3286	-3.2	-1.6
1.021	-16.5034	-8.7	-6.7
1.0169	-16.5343	0	0
0.9989	-16.7876	-3.5	-2.3
1.0226	-15.8557	0	0
1.006	-11.6949	0	0
1.0026	-16.0645	-2.4	-0.9
0.9911	-17.7786	-10.6	-1.9
Location of SVC is BUS Number: 24		Size of SVC is 9.1900 MVAR	

When BAT Algorithm is applied to the IEEE 30 bus system, it is found that the optimal location of SVC is at Bus 24 and the size of SVC is 9.19MVAR. It is observed from Table 2, when BAT algorithm is applied for IEEE 30 bus system, voltage profile is improved. When angle and active power are considered, there is no improvement. Reactive power is represented in the last column and it is found that there is an improvement in reactive power flow in specified buses due to the placement of SVC device.

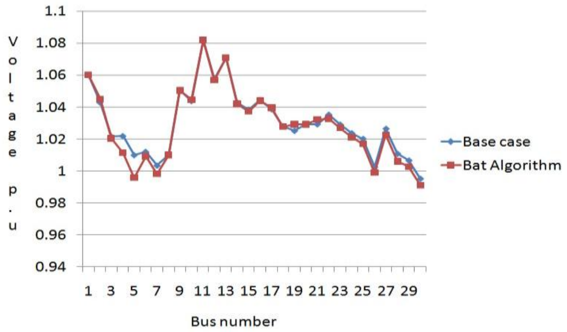

Figure 4: Voltage Profile of IEEE-30 Bus System with Base Case and Bat Algorithm

VII. CONCLUSION

In this paper an evolutionary algorithm (BAT Algorithm) method has been proposed to optimally locate SVC in power systems. Using the proposed BAT algorithm, with the optimization process subjected to equality and inequality constraints the voltage profile has been improved when compared with base case results. The proposed BAT algorithm is an effective method for the allocation of FACTS devices in power systems.

REFERENCES

[1] N. G. Hingorani and L. Gyugyi, *Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems* (Piscataway: IEEE Press, 1999.)

[2] J.G.Singh,S.N.Singh and S.C.srivastava, "*Enhancement of power system security through Optimal placement of TCSC and UPFC* ," *Power Engineering Society General Meeting ,Tampa,24-28 June 2007,* pp.1-6.

[3] S. Gerbex, R. Cherkaoui, and A. J. Germond, "*Optimal location of multi type FACTS devices in a power system by means of genetic algorithms*," *IEEE Trans.Power Systems, Vol. 16,* pp. 537-544,2001.

[4] BaldickR,Kahn E, "*Cotract paths,phase shifters and efficient electricity trade*", *IEEE TransactionsonPowerSystemsVol.12,No.2*,1997pp.749-755.

[5] Bladow j,Montoya A, "*Experience with parallel EHV phase shifting Transformers*" *IEEETransactions on power delivery*, 1991, pp.1096-1100.

[6] Galiana G.D , " *Assesment and control of the impact of FACTS devices on power system performance*",*IEEE Transactions on Power Systems,Vol.11,No.4*,1996,pp.1931-1936.

[7] J.G.Singh, S.N.Singh and S.C.Srivastava, "*Placement of FACTS controllers for enhancing FACTS controllers*",*IEEE 2006* .

[8] B.Battaacharya,B.S.K.Goswami,"*OptimalPlacement of FACTS Devices using Genetic Algorithm for the increeased loadability of a power system*",*World Academy Of Science and Technology* ,2011.

[9] R.M.Mathur,R.K.Varma,*ThyristorBasedFACTS Controllers for Electrical Transmission Systems* (JohnWiley&Sons Inc.,2002.)

[10] EnriqueA,FuerteEsquivel,C.R.Perez,H.A.*CamachoFACTS Modelling and Simulation in Power Network(*John Wiley &Sons Ltd,2004.)

[11] IEEE Special Stability Controls Working Group, "*Static VAR Compensator Models for Power flow and Dynamic Performance simulation*", *IEEE Transactions on Power Systems, Vol.9, No.1,* February 1994, pp 229-240.

[12] H.Ambriz-perez, E.Acha and C.R. Fuerte-Esquivel, "*Advanced SVC models for Newton–Raphson load flow and Newton Optimal Power flow studies*", *IEEE.*

[13] L.J.Cay, I.Erlich, "*Optimal choice and allocation of FACTS devices using Genetic Algorithms*",*IEEE*, 2004.

[14] M.Saravanam,S.MaryRajaSlochanal,P.V.Venkatesh,Prince Stephen Abraham.J, "*Application of PSO technique for optimal location of FACTS devices considering system loadability and cost ofinstallation*" *In:PowerEngineeringConference*,716-721.

[15] P.Muskapun and P.Pongacharoenl, " *Solving MultiStage,Multi Machine Multi Product SchedulingProblemusingBatAlgorithm*"*Proc .2nd International Conferenceon Management and Artificial Intelligence, Bangkok, Thailand, 2012,* pp.134-142 .

[16] James A.Momoh, M.E.El-Hawary, Rambabu Adapa, "*A Review of Selected Optimal Power Flow Literature to 1993 Part-I: Non-linear and Quadratic Programming approaches*", *IEEE Transactions on Power Systems, Vol. 14, No.1,* February 1999, pp. 96-104.

[17] X.S.Yang, "*New Metaheuristic Bat Insired Algorithm*",*Nature inspired Cooperative StrategiesforOptimizationStudiesinComputational Intelligence,Springer Berlin, 2010,* pp. 65-74.