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Optimal Location of Thyristor Controlled Series Capacitor Using Bat Algorithm

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***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, series device Thyristor controlled series capacitor (TCSC) is considered. The proposed BAT algorithm is a very effective method for the optimal choice and placement of TCSC device to improve the performance of power systems. The proposed algorithm has been applied to IEEE 30 bus system*.**

Index Terms— Thyristor controlled series capacitor, Flexible AC Transmission systems, BAT Algorithm.

I. INTRODUCTION

The secure operation of power system has become an important and critical issue in today's large, complex and load increasing systems. 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 flows 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. FACTS devices by controlling the power flows in the network without generation rescheduling or topological changes 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 controllable series capacitors 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 essentially 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 last decade, new algorithms have been developed for the optimal power flow incorporating FACTS devices as well as for the optimal placement of FACTS Devices. Some of them are: Sensitivity approach based on line loss has been proposed for placement of series capacitors, phase shifters and static VAR Compensators [8].Other works in optimal power flow with FACTS devices have used optimization with different objective functions. In, the optimal locations of FACTS devices are obtained by solving the economic dispatch problem and the cost of these devices making the assumption that all lines initially have these devices.

This paper proposes a new BAT based algorithm for optimal placement and sizing of TCSC unit. Simulations are performed to investigate the impact of TCSC of the IEEE-30 bus system. The proposed method shows the benefits of TCSC 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 TCSC [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,

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

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

Where V_i, V_j, δ_{ij} are the voltage magnitudes at bus-i and bus-j and voltage the 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

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

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

A. Static Representation of TCSC

The basic idea behind power flow control with TCSC is to decrease or increase the overall lines effective series transmission impedance, by adding a capacitive or inductive reactance correspondingly [14]. The TCSC is modeled as variable impedance, where the equivalent reactance of the line x_{ij} is defined as:

$$x_{ij} = x_{Line} \mid x_{TCSC}$$

Where, x_{line} is the transmission line reactance [12]. The level of applied compensation of the TCSC usually varies between 20% inductive and 70% capacitive. Fig 1.shows a controllable reactance $(-jx_{TCSC})$ placed in the transmission line connected between bus-i and bus-j.

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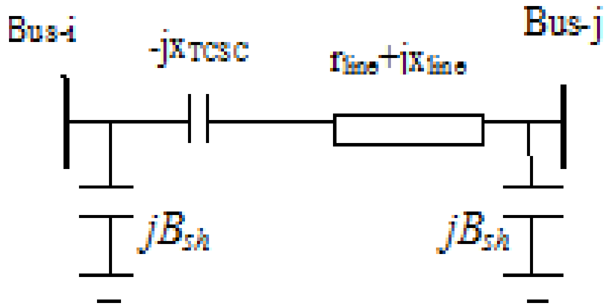

Figure1. Equivalent circuit of TCSC.

The real and reactive power flows from bus-i to bus-j and bus-j to bus-i in the line can be written with equations (1) to (4) with modified g_{ij} and b_{ij} as given below.

$$g_{ij} = \frac{r_{ij}}{r_{ij}^2 + (x_{ij} - x_{TCSC})^2}\ , \qquad b_{ij} = \frac{-(x_{ij} - x_{TCSC})}{r_{ij}^2 + (x_{ij} - x_{TCSC})^2}$$

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_{FACTS} number of strings, where n_{FACTS} is the number of FACTS devices to be optimally located in the power system [3], as shown in figure.

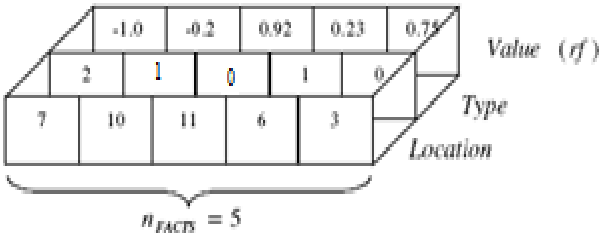

Figure 2. Individual configuration of FACTS devices

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_{type}) used. The values assigned to FACTS devices are: "1" for TCSC located in a line, "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 TCSC, and then the rated value generated between $-0.8\ X_{line}$ to $0.2\ X_{line}$.

To obtain population size of Bat Algorithm, the above operations are repeated n_I times, where n_I 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 branch loading (BL) maximization.

A. Branch Loading (BL) maximization

The objective is related to the branch loading and penalizes overloads in the lines [14]. This term, called BL, is computed for every line of the network. While the branch loading is less than 100%, its value is equal to 1; then it decreases exponentially with the load [6].

$$BL = \prod_{line} J_{line} \qquad (5)$$

$$J_{line} = \begin{cases} 1 & ;if\ S_{pq}^{max} \geq S_{pq} \\ e^{\left[\lambda\left(1-\frac{S_{pq}}{S_{pq}^{max}}\right)\right]} & ;if\ S_{pq} > S_{pq}^{mqx} \end{cases}$$

Where, *BL* is Branch Loading factor, S_{pq} and S_{pq}^{mqx} are MVA flow and thermal limit of the line between buses p and q. λ 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 overloaded transmission lines [3].Branch loading penalizes overloads in the lines.

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.

A. 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,

$$f_i=f_{min}+ (f_{max}-f_{min}) \beta \qquad (6)$$

$$V_i^t=V_i^{t-1}+(X_i^t-X_o)f_i \qquad (7)$$

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

Where $\beta \epsilon [0,1]$ 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 bats i generated locally using random walk.

$$X_{new}=X_{old}+\epsilon A^t \qquad (9)$$

Where $\epsilon €$ [-1,1] is a random number, while $A^t=<A_i^t>$ is the average loudness of all the bats at this time step. The flowchart of the generalized Bat algorithm is shown in Figure3.

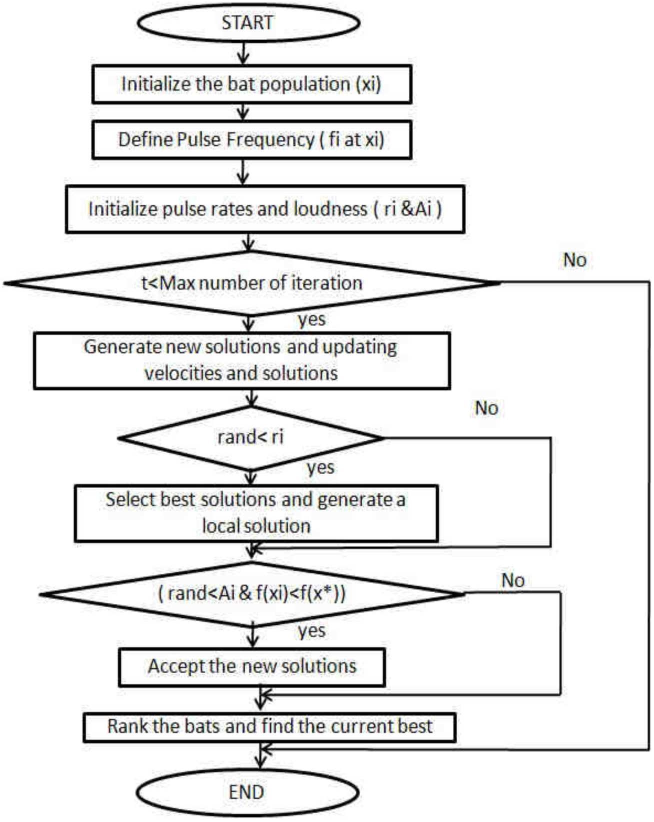

Figure 3: Flow Chart of the generalized BAT Algorithm

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 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 (TCSC), using BAT Algorithm. Fast decoupled load flow analysis is tabulated in Table I. The results for individual device (TCSC) Performance for the test case IEEE-30 bus system tabulated in the Table II. The optimal sizing and location of proposed FACTS device performance has shown in figure4.

Table I: 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

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When BAT algorithm is applied to the IEEE 30 bus system, it is found that optimal location of TCSC is in the line 10 which connects buses 6 to 8 and the size of TCSC is -0.2908 p.u.

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

TCSC for IEEE-30 Bus System			
BAT Algorithm			
V(p.u)	**Angle(δ)**	**P(MW)**	**Q(MVAR)**
1.06	0	262.2706	53.073
1.0071	-4.8613	18.3	-75.2498
1.0123	-7.6239	-2.4	-1.2
1.0014	-9.409	-7.6	-1.6
1.01	-14.5427	-94.2	40.9258
1.0031	-11.2901	0	0
0.9981	-13.1563	-22.8	-10.9
1.01	-12.1625	-30	27.1577
1.0467	-14.3606	0	0
1.0402	-15.9611	-5.8	-2
1.082	-14.3606	0	18.3834
1.0529	-15.1821	-11.2	-7.5
1.071	-15.1821	0	13.87
1.0379	-16.0847	-6.2	-1.6
1.0332	-16.1786	-8.2	-2.5
1.0398	-15.7758	-3.5	-1.8
1.0351	-16.1214	-9	-5.8
1.0243	-16.8028	-3.2	-0.9
1.0209	-16.9808	-9.5	-3.4
1.0249	-16.7837	-2.2	-0.7
1.0278	-16.408	-17.5	-11.2
1.0283	-16.3937	0	0
1.0224	-16.578	-3.2	-1.6
1.0165	-16.7634	-8.7	-6.7
1.0119	-16.343	0	0
0.9941	-16.7673	-3.5	-2.3
1.0176	-15.8207	0	0
1.0013	-11.9436	0	0
0.9977	-17.0645	-2.4	-0.9
0.9861	-17.9576	-10.6	-1.9
Location of TCSC isLine10:6-8		Size of TCSC is -0.2908 p.u	

It is observed from Table II, when Bat algorithm is applied for IEEE 30 bus system, Voltage profile is improved. When angle and active power are considered, there is little improvement at few buses. 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 TCSC device.

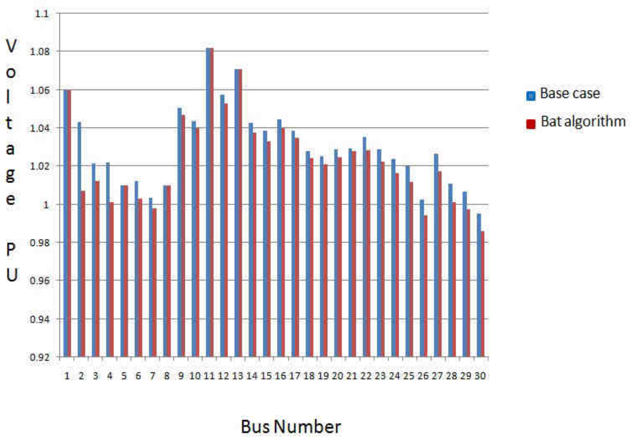

Figure4. Voltage profile of IEEE-30 bus System with base case and BAT Algorithm

VII. CONCLUSION

In this paper an evolutionary algorithm (BAT Algorithm) method has been proposed to optimally locate TCSC 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 to base case results. The proposed Algorithm is an effective method for the allocation of FACTS devices in large power systems

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