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A Distinctive Selection of FACTS Devices for Static Security Enhancement in Power systems

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Abstract— **Flexible Alternating Current Transmission Systems (FACTS) devices have been projected as effectual control in Real and reactive power flows and regulating bus voltage in most of the power system networks or models, as a result reduction in losses, and maintaining stable operating condition in almost contingent situations. Placement of such a FACTS devices in suitable location and capacity can lead to control in line flow and maintain bus voltages at desired level and to improve power system security. This paper presents a novel algorithm for optimal allocation and Sizing of FACTS devices based on biogeography based optimization Algorithm. The proposed algorithm is tested with IEEE 30 bus power system.**

Keywords: *FACTS, Biogeography based Optimization, Security enhancement, Steady state Security Assessment, TCSC*

I INTRODUCTION

In larger interconnected power system, each of the control centers is responsible for the control of a given segment of the whole system. Most of the control centers, which receives the telemetered data and estimates the electrical status of the controlled portion through power flows, voltage magnitudes and check their specified limits. so power system control processes needed to maintain a designated security level at minimum operating cost .Now days, modern control centers can able to predict the new system security status rapidly even considering specified contingencies[2]. In static security enhancement ,it is mandatory to clear all the obscurity throughout observation and done by enrichment activities via FACTS devices.

A quick security evaluation of power system will forewarn the operators that the system is in-secure under certain condition and that appropriate secure under definite conditions after that appropriate precautions or actions should be taken quickly. So, there is a pressing in further for security enhancement of power systems. The Present work mainly focuses on steady state security enhancement via FACTS.

FACTS devices [9,10,12,14] based on power electronics represents an active tool for the control of active power as well as reactive power or else voltage control. A good coordination between FACTS devices and the conventional power system control devices is necessary to make the power systems operates under secure in economic way. From the literatures, A flexible method of security enhancement by examining the sensitivity of the security margin to various control actions. The potential application of security evaluation along with security constrained OPF has been presented[9].The applications of steady state approaches to the voltage assessment of the electric system and to determine the control actions suitable to avoid the voltage collapse has presented. An suitable on-line methodology for the preventive control of voltage instability by promptly rescheduling control settings to accommodate the load increase have proposed. however, these models too suffer from certain inherent drawbacks including online adoptability.

This paper mainly focuses on optimal location and optimal setting of FACTS device namely, Thyristor Controlled Series Compensation (TCSC) for security enhancement taking minimization of voltage magnitude violations and control the line overloading limit. The presence of multiple objectives in a problem gives rise to a set of optimal solutions[15]. However, it is hard to determine the optimal allocation of TCSC due to the complicated combinatorial optimization.

In this consequence, the proposed BBO algorithm is optimally allocate the FACTS devices to enhance the security level. The effectiveness and potential of the proposed approach has been demonstrated using IEEE 30-bus system.

II SECURITY ENHANCEMENT

The operation of power system involves many interrelated studies such as load flow studies, stability studies, fault analysis, economic dispatch, unit commitment, maintenance planning, spinning and reserve requirement, load frequency control, load forecasting ,etc.

A power flow is strictly governed by the electric network equations. The flow pattern depends mainly on the load and the generation distributions and the network configuration. The amount of power generated by each unit is constrained by it capacity. The power flowing in each line is limited by its rating and so is that handled by each transformer. For security evaluation, constraints may impose on the bus voltage angle across the lines[2]. Voltage-levels are to be within acceptable range. All the preceding conditions may be expressed in the following mathematical equalities and inequalities.

$$P_{Gi} - P_{Li} = V_i \sum_{j=1}^{n} V_j Y_{ij} Cos(\delta_i - \delta_j - \theta_{ij}) \qquad (1)$$

$$Q_{Gi} - Q_{Li} = V_i \sum_{j=1}^{n} V_j Y_{ij} \sin(\delta_i - \delta_j - \theta_{ij}) \qquad (2)$$

$$PG_{Maxi} \geq PG_i \geq PG_{Mini} \qquad (3)$$

$$QG_{Maxi} \geq QG_i \geq QG_{Mini} \qquad (4)$$

$$V_{Maxi} \geq V_i \geq V_{Mini} \qquad (5)$$

$$\alpha_{ij} \geq \left|\delta_{ij}\right| = \left|\delta_i - \delta_j\right| \qquad (6)$$

$; \; i = 1, 2 \ldots . n \;\; / j = i+1 \ldots n$

The above equalities and inequalities *(1)-(6)*, may be expressed in compact form,

$$g(x,u) = 0 \; ; \; h(x, u) \leq 0 \qquad (7)$$

where ***u*** is a set of independent variables and ***x*** is a set of dependent variables, the constraints ***g(x,u)=0*** and ***h(x,u) ≤ 0***, are satisfied, the power system is said to be in the normal operating state. Likewise the constraints ***g(x,u)=0*** are satisfied and inequality constraints ***h(x,u) ≤ 0*** is violated, it said to be in the emergency state. the subset of equality constraints ***g(x,u) = 0*** is violated and all the inequality constraints ***h(x, u) ≤ 0*** are satisfied, the power system is said to be in the restorative operating state[3,9].

Suppose that, a power system persists in the normal operating state is subjected to the set of disturbances such as a single line outage, loss of generator, sudden loss of load, and sudden change of power flow in inter-tie, then the system condition is said to be secure, otherwise ,it is insecure.

III FACTS DEVICES

FACTS is a static equipment in AC transmission to enhance controllability and increase power transfer capability. it can be alienated in to some faction based on their switching technology, i.e. mechanically switched (such as phase shifting transformers), Thyristor switched or fast switched, using IGBTs. In this connection, Phase shifting transformer (PST) and the static VAR compensator (SVC) are well known FACTS devices used for enhancement purpose in Power system[10].

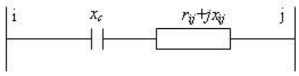

Figure 1.Equivalent circuit of TCSC

TCSC consists of a fixed capacitor in parallel with a thyristor controlled reactor as illustrated in Figure.1. The primary function of the TCSC is to provide variable series compensation to a transmission line, which exhibit power flows due to change in series reactance[11].

The model of transmission line with TCSC connected between buses ***'i'*** and ***'j'*** is shown in Figure.1. For steady state analysis, the TCSC can be considered as a static reactance ***-jxc***. The controllable reactance $\boldsymbol{x_c}$ is directly used as the control variable in the power flow equations. The power flow equations of a transmission line with TCSC can be written as

$$P_{ij} = Vi^2 g_{ij} - V_i V_j (g_{ij} cos\delta_{ij} + b_{ij} sin\delta_{ij}) \qquad (8)$$

$$Q_{ij} = - Vi^2 b_{ij} - V_i V_j (g_{ij} sin\delta_{ij} - b_{ij} cos\delta_{ij}) \qquad (9)$$

Where ,$G_{ij} = r_{ij} /(r_i^{j2} + (x_{ij} - x_c)^2); \; b_{ij} = x_{ij} - x_c /(r_{ij}^2 + (x_{ij} - x_c)^2)$

Here, the controllable reactance $\boldsymbol{x_C}$ is a inductive /capacitive compensation component has present and identified as a line with TCSC and a line flow without TCSC.

The TCSC reactance is given by

$$X_C = X_{TCSC}.x_{line} \qquad (10)$$

Where, x_{line} is the reactance of the transmission line and x_{TCSC} is the coefficient which represents the degree of compensation by TCSC.

To avoid the overcompensation, the working range of the TCSC is chosen between ***-0.5 X** **line*** and ***0.5 X** **line*** [13,14].

Consider an optimization problem which has one or more objective functions are minimized while satisfying a number of equality and inequality constraints alongside finding the optimal location and the optimal parameter setting of TCSC device under single contingency.

IV BIOGEOGRAPHY-BASED OPTIMIZATION

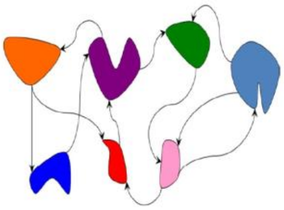

Figure. 2 Species migrate between islands

The Basic structure of biogeography in Figure 2 describe how species migrate from one island to another, how new species arise, and how species become extinct. The term "island" here is used descriptively rather than literally. That is, an island is any habitat that is geographically isolated from other habitats. So, therefore use the more generic term called "habitat". Geographical areas that are well suited as residences for biological species are said to have a high habitat suitability index (HSI). Features that correlate with HSI include such factors as rainfall, diversity of vegetation, diversity of topographic features, land area, and temperature. The variables that characterize habitability are called suitability index variables (SIVs). SIVs can be considered the independent variables of the habitat, and HSI can be considered the dependent variable[8].

Habitats with a high HSI tend to have a large number of species, while those with a low HSI have a small number of species. Habitats with a high HSI have many species that emigrate to nearby habitats, simply by virtue of the large number of species that they host. Habitats with a high HSI have a low species immigration rate because they are already nearly saturated with species. Therefore, high HSI habitats are more static in their species distribution than low HSI habitats. By the same token, high HSI habitats have a high emigration rate; the large numbers of species on high HSI islands have many opportunities to emigrate to neighboring habitats. i.e. an emigrating species completely disappears from its home habitat; only a few representatives emigrate, so an emigrating species remains extant in its home habitat, while at the same time migrating to a neighboring habitat.

Habitats with a low HSI have a high species immigration rate because of their sparse populations. This immigration of new species to low HSI habitats may raise the HSI of the habitat, because the suitability of a habitat is proportional to its biological diversity. However if a habitat's HSI remains low, then the species that reside there will tend to go extinct, which will further open the way for additional immigration. Due to this, low HSI habitats are more dynamic in their species distribution than high HSI habitats[12].

V METHODOLOGY

A. *Objective Function*

$$F_t = \sum_{i=1}^{ntl} Wl\left(\frac{S_l}{S_{l\max}}\right)^{2q} + \sum_{m=1}^{nb} Wm\left(\frac{V_{mref} - V_m}{V_{mref}}\right)^{2r} \qquad (11)$$

where S_l and S_{lmax} represent the current apparent power the maximum apparent power of line *l*, respectively; *Vm* represents the voltage magnitude at bus *m*; *Vmref* represents the nominal voltage at bus *m*; *wl* and *wm* represent two weighting factors which are determined in order to have the same index value for 10% voltage difference and for 100% branch loading; *q* and *r* represent two coefficients which are used to manage overloads and voltage variations, respectively; *ntl* and *nb* represent the number of lines and the number of buses in the system[15,16]

B. *Optimal location and setting of TCSC*

The proposed methodology is outlined for eliminating or alleviating the line overloads and minimizing the installation cost of TCSC. the sequence has been formulated as,

- Load flow analysis with single line outages.
- Placement of FACTS devices (TCSC).
- Evaluate Severity index
- Optimizing the parameters for optimal setting and optimal placement of TCSC.

C. *Implementation of BBO for optimal Setting and Optimal Location*

- Read power system data such as line data, bus data, and load data.
- Compute initial number of population in the habitat. (No.of.Buses and Lines).
- Evaluate the value of fitness function (TCSC modeling function) using the immigration operator.
- Fix the fitness population (TCSC reactance value) using emigration operator.
- Mutate and Migrate the best population to the new habitat(Best TCSC Reactance Values)
- If the condition is satisfied process will be terminated, else re-iteration should be performed till the fitness function is perfectly fitted.

To assess the severity of the contingency represented by the population in the above procedure, contingency analysis and selection is performed, and Performance Indexes associated are calculated[13].

Severity index (PIF*l*) is calculated as,

$$PIFl = \sum_{i=1}^{v} \frac{pmw(l)^2}{cmw(l)^2} \qquad (11)$$

Pmw – Power flow at branch *l; Cmw* – Power capacity at branch *l;* *v* – Number of overloaded branches

The voltage monitoring index (*PIV*) is calculated as follows

$$PIV = \sum_{b=1}^{n} (VIOLt(b))^2 \; X\, 10^4 \qquad (12)$$

VIOLt(b) – Voltage violation at bus *b;V(b)* – voltage magnitude at bus *b (pu); n* – Number of buses with voltage violations.

VI SIMULATION RESULTS AND DISCUSSION

A. *Data Generation for IEEE 30 Bus Test system*

The standard IEEE 30 bus sample system has 6 generators, 30 buses, 41 lines and 6 condensers[17]. The patterns or variables are generated from the load flow results considering all possible contingencies. The generated variable set consists of 24 numbers of voltage magnitude variables (Vi), 29 numbers of voltage angle (δi), 6 numbers of real power generation variables (PGi), 6 numbers of reactive power generation variables (QGi), 20 numbers of real power demand variables (PDi), 20 numbers of reactive power demand variables (QDi), 41 numbers of active real power flow variables (Pi-j) , 41 numbers of reactive power flow variables (Qi-j) and 40 numbers of line MVA variables (Si-j). Finally, 227 numbers of most significant patterns are obtained for classification process out of which 6 numbers of real power generation variables (PGi), 6 numbers of reactive power generation variables (QGi) totally 12 numbers of patterns are subjected to SSA[17]. The IEEE 30 bus system has 904 operating scenarios, in which 753 operating scenarios are found to be secure and the remaining 151 cases are found to be insecure.the location and ratings of TCSC were optimized and the objectives such as VSI, SSI are minimized.

Table. 1 Contingency selection without TCSC

Congested Line		Voltage marginal limit	Line MVA
1	2	176.1053	130
22	24	20.33441	16
24	25	19.49419	16
1	2	176.1053	130
22	24	20.33441	16
24	25	19.49419	16
1	2	175.0292	130
1	2	157.8561	130
2	4	71.21987	65
4	6	115.8168	90
6	8	35.90918	32
1	2	175.1674	130
6	8	46.16704	32
1	2	174.5732	130
6	8	32.41103	32
1	2	175.1092	130
1	2	175.3306	130
1	2	271.075	130
2	4	84.88158	65
2	6	91.76717	65
6	8	34.94487	32
1	2	174.7701	130
1	2	175.3337	130
1	2	174.559	130
1	2	175.3821	130
1	2	175.1327	130
1	2	200.5759	130
2	6	98.56448	65
4	12	67.5536	65
1	2	175.2001	130
1	2	175.1138	130
1	2	174.9995	130
1	2	185.8182	130
1	2	172.3631	130
1	2	175.2146	130
6	8	32.70463	32
1	2	175.0239	130
1	2	165.4421	130
2	4	74.66518	65
2	6	102.9619	65
4	6	123.6755	90
5	7	110.1006	70
6	8	35.415	32
1	2	175.0732	130
1	2	175.3074	130
1	2	175.0651	130
1	2	175.691	130
8	28	33.07907	32
6	28	48.18708	32
1	2	175.1887	130
15	18	16.3236	16
1	2	175.1042	130
1	2	158.4282	130
2	6	79.81459	65
6	8	33.98998	32
1	2	175.0292	130
1	2	175.2771	130
1	2	174.9995	130
1	2	175.3074	130
1	2	176.1053	130
22	24	20.33441	16
24	25	19.49419	16
1	2	175.4234	130
1	2	174.559	130
1	2	274.0264	130
2	4	86.12033	65
2	6	92.7203	65
6	8	35.25674	32

Table. 2 Contingency ranking without TCSC

Line No.	From Bus	To Bus	Vi	Pi	Ranking
36	28	27	177.5304	**5.9725**	*1*
36	28	27	177.5304	4.2914	*2*
36	28	27	177.5304	4.2914	*3*
38	27	30	2.1227	4.2914	*4*
38	27	30	2.1227	3.7303	*5*
4	3	4	1.2379	3.6036	6
11	6	9	1.2206	3.5076	7
18	12	15	1.2047	3.3431	8
19	12	16	1.0835	3.1759	9

Table.3 the optimal set of Real and Reactive power losses, optimal location and Setting

Real power losses in p.u	**0.0011**
Reactive power losses in p.u	**8.68E^{-04}**
Optimal location of TCSC (line number)	**12**
Reactance of TCSC(X_{TCSC})	**0.648**

Table 1,2 and 3 shows and comprises one set of optimization results which ensures optimal X_{Tcsc} value and optimal location. after modification in IEEE 30 bus system responds and together produces system status , contingency selection and contingency ranking.

CONCLUSION

This paper presents a unique approach for static Security Enhancement using IEEE 30 bus system. The computation of secure and sensitivity operating point have been tested on IEEE 30Bus system and compared with and without implement of TCSC using BBO algorithm. Based on the Results, The location and Settings of TCSC is optimally identified by BBO which validates the voltage profile is enhanced at all buses and power losses are considerably decreased by considering the objectives such as minimization of VSI, SSI, minimization of power losses.

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