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Optimal Location of multi-type FACTS for Power System Security Enhancement

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ABSTRACT---Transmission congestion results from the contingencies in the power system and increasing load demand that has to be supplied through predetermined corridors in case of restructured environment. The Flexible AC Transmission Systems (FACTS) devices when deployed in a power system can result in improving the system performance in terms increased loading capability of transmission lines, reduction in losses, improved stability and security of the system by relieving stress on congested lines. This work deals with congestion management of the power transmission network by employing FACTS devices, with the help of Genetic Algorithm (GA) based optimization algorithm. Optimal location of FACTS placement and optimal parameter settings of these devices are the objectives for the optimization problem. The optimization process aims at maximizing the loading capability by the network by transferring power from overloaded lines to adjacent lightly loaded lines. FACTS devices considered are TCSC, SVC and UPFC for the alleviation of the overload on transmission lines and to reduce overall transmission loss of the system. An IEEE 30-bus system is used to illustrate the effectiveness of the proposed method.

Keywords - congestion management; FACTS; Optimal Location; Genetic Algorithm;

I. INTRODUCTION

Restructuring Ensuring security of power system is of major concern during load dispatch and is implemented using Security Constrained Optimal Power Flow (SCOPF). The SCOPF has the objective of finding an optimal operating point that minimizes an objective function, making sure that any contingency in the system does not result in congestion. The SCOPF problem has been solved using classical optimization techniques like Gradient method [1] and Newton's method. However, the short comings of these techniques are that many control variables may not lead to the global optimum and discrete values in search space also contributes to this.

Optimal Power Flow (OPF) based congestion management ensures that under outage of any single element of any kind will not cause any limit violation in the system. Moreover, the values of controllable system parameters are decided optimally in order to satisfy all the necessary constraints like load balance, reduced losses and minimum operating costs. This is achieved only at the cost of increased dimension of the problem, making it more difficult while using analytical methods. Hence, evolutionary algorithms like Genetic Algorithm are used to overcome the short comings of the conventional techniques.

Satisfying the security constraints during contingencies is complex as one or more transmission lines may be overloaded. The task of congestion management in a restructured market is more complex as the contracted paths for power transfer should only be dealt in the process. Hence, existing corridors for power transfer need to be expanded, but involve many environmental, cost and right-of-way problems, that need to be addressed. Some of these objectives can be implemented using controllers such as Flexible AC Transmission Systems (FACTS). FACTS devices can act as one of the alternatives in improving the system performance in terms increased loading capability of transmission lines, reduction in losses, improved stability and security of the system by relieving stress on congested lines.[2],[8]. FACTS devices help in maintain the voltages or managing the flows in the transmission lines either by absorption or supply of reactive power, or by controlling series impedance or phase angle, enabling the transmission lines to operate near thermal limits, maintain better voltage profile at the buses and lower the transmission line losses. Basically, the type of the FACTS device decides the nature of benefit obtained, size of the device, its number and location in the system also play a key role in obtaining the overall effect of the considered FACTS device [3]. Many techniques are reported in the literature explaining various placement methods of FACTS devices [4-6].

Genetic algorithm is hence used in this work to optimally decide the type, location and its compensation value of FACTS devices in order to address the contingencies in the considered IEEE 30 bus system. TCSC for series compensation and SVC for shunt compensation are the selected FACTS devices for the purpose.

This article is organized as follows. The modeling of FACTS devices based on the Injected power model is described in section II. Problem formulation is explained in section III, explaining the objective function and related constraints. Section IV illustrates the algorithm used for congestion management, with the help of optimization process that is used. Case study and results are dealt in section V, followed by conclusions of the work.

II. FACTS DEVICES: STATIC MODELLING

FACTS devices are modelled using Injected-power model in order to be used in power flow and optimal power flow calculations [7].

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A Thyristor Controlled Series Compensator (TCSC) is chosen from the group of series FACTS controllers, a Static Var Compensator (SVC) from the group of shunt FACTS controllers and Unified Power Flow Controller (UPFC) is chosen from the third group of FACTS devices, combined shunt-series controllers.

A. Thyrisyor Controlled Series Capacitor (TCSC)

The TCSC (Thyristor Controlled Series Capacitor) modifies the reactance of the transmission line in which it is placed in series and hence provides both capacitive and inductive compensation. Reduction of line reactance results in capacitive mode and increasing reactance results in inductive mode as shown in Figures 1 and 2. The rating of TCSC is determined by the reactance of the transmission line as well as the reactance of TCSC.

The rating of the TCSC is formulated by a coefficient k_{TCSC} as (1) and the limit to which reactance can be reduced or increased is line given by (2).

$x_{TCSC} = k_{TCSC}.\ x_{ij}$ (1)

$-0.95 \le k_{TCSC} \le 0.2$ (2)

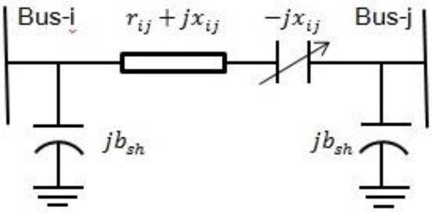

Figure 1. Branch with TCSC installation

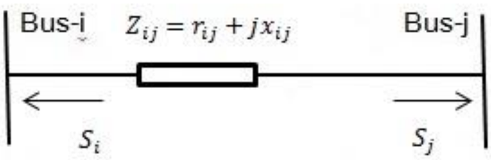

Figure 2. Branch with TCSC equivalent Injection model

B. Static Var Compensator (SVC)

The SVC (Static Var Compensator) supplies or absorbs reactive power to the bus at which it is connected in shunt. It supplies reactive power during capacitive mode and absorbs during inductive mode. SVC consists of a shunt susceptance connected by two ideal switched elements in parallel: it is the switching angles of these switches that make the shunt susceptance to work in either inductive mode or capacitive mode. The reactive power injected or absorbed by the SVC at a voltage of 1 p.u. (rated system voltage) could change between the following values (3), owing to the maximum requirement of reactive power of the system for its weakest bus to gain normal voltage profile.

$-31 \le Q_{SVC} \le 31$ MVar (3)

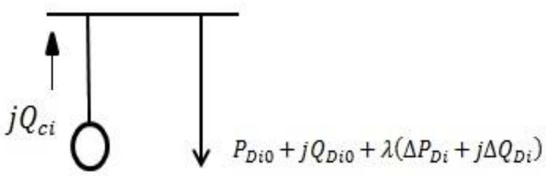

Figure 3. Power Flow at a Bus

The power flow at a bus, i to which SVC is connected is shown in Figure 3. Loading factor λ is considered as the amount by which the change in system demand is modelled for an equivalent injection due to SVC. (3) and (4) represent the load balance equations corresponding to real and reactive powers at a PQ bus i.

$\Sigma P_{ijc} + P_{Di0} + \lambda\Delta P_{Di} = 0$ (4)

$\Sigma Q_{ijc} + Q_{Dio} - Q_{ci} + \lambda\Delta Q_{Di} = 0$ (5)

If bus i is assumed to be a PV bus, the expressions for power balance are given using (6) and (7).

$\Sigma P_{ijc} - P_{Gi} - P_{Gi0} + P_{Di0} + \lambda\Delta P_{Di} = 0$ (6)

$\Sigma Q_{ijc} - Q_{Gi} - Q_{Gi0} + Q_{Di0} + \lambda\Delta Q_{Di} = 0$ (7)

where,

P_{ijc} and Q_{ijc} are real and reactive line flows through line i-j

$-P_{Gi0} + P_{Di0}$ and $-Q_{Gi0} + Q_{Di0}$ are the base real and reactive injections at the bus

P_{Di} and Q_{Di} are the loading levels for the load at the bus to increase

$P_{Gi}$and Q_{Gi} are the additional real and reactive power generations for providing increased system load.

C. Unified Power Flow Controller (UPFC)

The UPFC (Unified Power Flow Controller) is supposed to perform the combined function of both series FACTS and shunt FACTS controllers. It is going to modify the flow through the line in which it is placed through series impedance and also modifies the voltage at a bus by absorbing or supplying reactive power to the bus to which it is connected. In addition, it is also going to provide the change on phase angle to enhance the properties of the power system whenever desired. Hence UPFC van be modelled by Power Injection model concept as a combination of both the above types of devices including a phase shifter. UPFC is therefore a combination of TCVR (Thyristor-Controlled Voltage Regulator) and TCPST (Thyristor-Controlled Phase Shifting Transformer) and parallel device SVC, working simultaneously. In order to locate UPFC in the network, TCVR and TCPST are located in series with the branch, SVC will be located in shunt to the adjacent bus of the considered transmission line.

The TCVR (Thyristor-Controlled Voltage Regulator) can be modelled as an in-phase voltage injection into the branch in which it is connected, using an ideal tap changer transformer without series impedance. The TCVR coefficient $k_{TCVR}$is modelled to inject a voltage as given in (8) and (9).

$V_{TCVR} = k_{TCVR} .V_{bus}$ (8)

$-0.1V_{bus} \le V_{TCVR} \le 0.1\ V_{bus}$ (9)

$-0.1 \le k_{TCVR} \le 0.1$ (10)

The TCPST (Thyristor-Controlled Phase Shifting Transformer) can be modelled as an ideal phase shifter with series impedance equal to zero. The phase angle of voltage can be regulated by injecting the phase angles in the range indicated by (11).

$-5° \le \delta_{TCPST} \le 5°$ (11)

III. PROBLEM FORMULATION

The main objective of the problem is to minimize the power flow through the overloaded lines.

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And, in order to achieve the objective, control parameters like optimum location for the installation of the FACTS device and the compensation value for that device by which the combination of these objectives gives the minimum power flow through the overloaded line need to be determined.

Once the overloaded lines are relieved of the excess power to flow through them, there is a less chance of congestion, further a cascaded outage can be avoided, thus enhancing the security of the system.

Objective function:

Minimize flow through overloaded line i-j (S_{ij})

The adjustable system quantities such as location and size of the compensation device are the control variables. Hence, the optimization problem outputs the location and compensation of the selected FACTS device in order to address the congestion.

The following are the two categories of constraints that the optimization problem should abide to:

Equality Constraints

The equality constraints guarantee the balance in power at every node during power flow. The equality constraints of the model are described by the real and reactive power equations as described [10]. Also, the active power of generator and demand has to be adhered as per the equations for market equilibrium.

Active and Reactive Power balance

$$\boldsymbol{P_{gk} - P_{dk} = \sum_{j=1}^{n_b} |V_j||V_k||Y_{kj}| \cos(\delta_k - \delta_j - \theta_{kj})}$$

$$\boldsymbol{Q_{gk} - Q_{dk} = \sum_{j=1}^{n_b} |V_j||V_k||Y_{kj}| \sin(\delta_k - \delta_j - \theta_{kj})}$$

P_{gk}, Q_{gk}
$- Real\ and\ reactive\ power\ generated\ at\ bus\ number\ k$
P_{dk}, Q_{dk}
$- Real\ and\ reactive\ power\ demands\ at\ bus\ number\ k$
$Y_{kj} - Bus\ Admittance\ between\ nodes\ k\ and\ j$
$V_j, V_k - Bus\ voltages\ of\ buses\ j\ and\ k\ respectively$
δ_j, δ_k
$- Bus\ voltage\ angles\ of\ buses\ j\ and\ k\ correspondingly$
θ_{kj}
$- Bus\ admittance\ angle\ of\ line\ connected\ between\ j\ and\ k.$
$n_b = Number\ of\ buses$
$n_g = Number\ of\ generators$
$n_d = Number\ of\ demands$

D. Inequality Constraints

The inequality constraints govern the operating bounds of the system pertaining to the line flow (active and reactive power), voltages (generators and load buses) and the apparent power of transmission lines and transformers. Also, they enforce limits on the controlling variables.

(a) Generator Active Power Limits

$$P_{gimin} \le P_{gi} \le P_{gimax}$$

$gi\ refers\ to\ the\ number\ of\ generator\ buses$

(b) Generator Reactive Power Limits

$$Q_{gimin} \le Q_{gi} \le Q_{gimax}$$

(c) Generation Voltage Limits

$$V_{gimin} \le V_{gi} \le V_{gimax}$$

Load Bus Voltage Limits

$$V_{Limin} \le V_{Li} \le V_{Limax}$$

$Li\ refers\ to\ the\ number\ of\ Loadbuses$

(d) Line Flow Limits

$$S_L \le S_{Lmax}$$

(e) TCSC constraint: Reactance of TCSC

(f) SVC constraint : Reactive power injected by SVC

(g) TCVR and TCPST constraints : Voltage magnitude and phase angle injected by UPFC

The constraints of TCSC reactance and reactive power injected by SVC are given in (2) and (3) respectively, and that of TCVR and TCPST are given by (10) and (11).

IV. ALGORITHM FOR CONGESTION MANAGEMENT

Genetic algorithm is a metaheuristic computational model inspired by natural selection, belongs to the class of evolutionary algorithms, and hence is a part of artificial intelligence. The genetic algorithm searches for a better and better solution as it creates and tests each population of chromosomes. It tries to improve upon its solution efficacy by various processes like crossover, mutation.

The problem of Congestion management here is solved using GA. The required solution is encoded in the form of binary bits, representing the type of device, location and compensation of the device selected. The algorithm is depicted as follows:

1) Run load flow with/ without contingency by Newton Raphson method.

2) Calculate number of overloaded lines based on the given limits.

3) For every overloaded line, the following process is repeated.

a) Generation of initial population

b) Calculation of integer values corresponding to type of device, location and compensation

c) Placing the calculated values in the data i.e. bus data/branch data

d) Run load flow by Newton Raphson method

e) Store the value of absolute power flow through over loaded line

f) Repeat the process for all strings of population

g) Find out power flow of overloaded line from the stored power flows which is suitable for the given limits and store the corresponding integer values of the string which are type of device, location, compensation, etc.,

h) Perform operations of genetic algorithm i.e. selection, crossover and mutation

i) Repeat above procedure for the number of iterations given and select the best solution

4) Repeat the above procedure for all the overloaded lines listed

5) Print the solutions for different overloaded lines.

V. CASE STUDY AND RESULTS

IEEE 30 bus system, with six generators as shown in Figure 4 is used to illustrate the method of congestion management using GA. Three types of FACTS devices are used for placement to resolve the congestion of power flow through over loaded lines and the FACTS devices used for the problem are TCSC, SVC and UPFC.

String or the individual in GA represents one of the possible solutions in the population. Binary encoding of the string is opted in this case. The length of the string is taken equal to 27, into which three unknown variables to be optimized are encoded. The first unknown variable is the type of FACTS device which gives the best fitness value, the next variable corresponds to optimum location (line/bus) for the installation of the FACTS device and the last variable is the amount of compensation to be given for that FACTS device.

Location represents line/bus at which the chosen FACTS device is to be placed. Higher two bits are allocated to indicate the type of the device as TCSC, SVC and UPFC. As the encoding is done in binary, three devices can be represented using two bits in binary form.

The number of lines and buses in IEEE 30 bus system are 41 and 30 respectively. In order to represent these numbers, the next six bits are used to denote the location of the device, line number for a series device and the bus number for a shunt device.

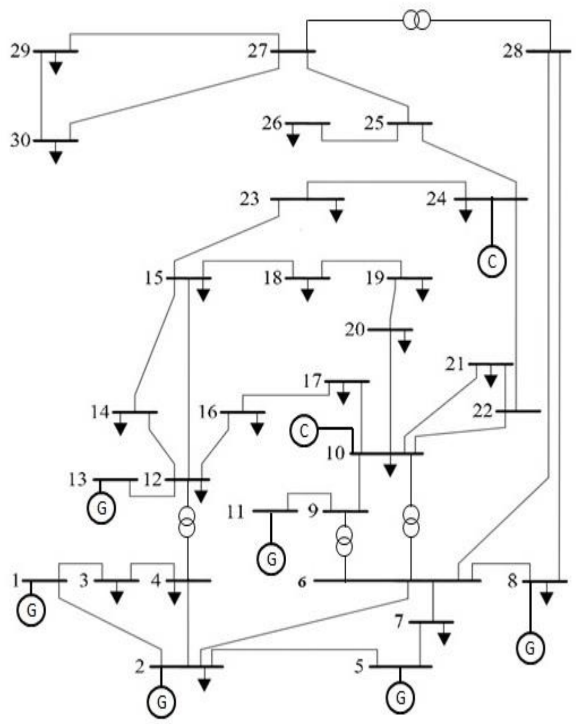

Figure 4.IEEE 30 bus system

Of the remaining nineteen bits of the string, five bits are used to represent the compensation offered by SVC, seven bits are used for TCSC. As UPFC is a combination of SVC, TCVR and TCPST, five, eleven and three bits are respectively allotted for these devices in UPFC as indicated in Table I.

Line outages are the considered contingencies in the case study. All line outages are created to identify the most severe contingencies. Table II lists the most severe contingencies, depicting the overloaded lines with the amount of overload.

Congestion management method using FACTS devices is basically tested for most severe contingencies so that, all other contingencies are taken care by default. Table II represents the location and compensation values of the FACTS devices considered for the most severe contingencies. The location and compensation are the results obtained by GA.

TABLE I. LIST OF SEVERE CONTINGENCIES

Type of FACTS device	No. of bits allotted in String For **Type of device**	No. of bits allotted in String For **Location of device**	No. of bits allotted in String For **Compensation value of device**
TCSC	2	6	7
SVC	2	6	5
UPFC (SVC + TCVAR+TCPST)	2	6	5 + 11 +3

TABLE II. LIST OF SEVERE CONTINGENCIES

S. No.	Contingency	Overloaded Lines	% of Power Flow
1	8-28	6-8	134.8
2	28-27	6-8	112.08
3	23-24	6-8	109.26
4	4-12	6-8	108.88

TABLE III. OPTIMUM SOLUTIONS FOR SEVERE CONTINGENCIES

Method	Contingency	Overloaded Line	Device	Optimal Location	Optimum Compensation
Single Type	8-28	6-8	TCSC	-	-
	28-27	6-8		8-28	-0.92
	8-28	6-8	SVC	6-8	30
	28-27	6-8		6-8	14
	8-28	6-8	UPFC	6-8	30 0.931 -5
	28-27	6-8		6-8	31 1.07 3
Multi Type	8-28	6-8	UPFC	6-8	30 0.903 -1
	28-27	6-8	SVC	6-8	14

As stated earlier, FACTS devices have multiple uses. Placing of these devices not only improves security by reducing congestion, also results in lower operation losses of the system. Table III represents the reduction in losses on placing these FACTS devices optimally.

The blank column for contingency 8-28 in Tables 2 and 3 indicate that placement of TCSC in any line is not sufficient to address that congestion.

TABLE IV. PARAMETERS OF OVER LOADED LINES BEFORE AND AFTER PLACEMENT OF FACTS

Method	Device	Contingency	Power Flow		Power Loss	
			Before FACTS	After FACTS	Before FACTS	After FACTS

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Single Type	TCSC	8-28	-	-	-	-
		28-27	35.875	29.764	3.083	3.066
	SVC	8-28	43.142	30.098	2.683	2.247
		28-27	35.875	28.811	3.083	2.837
	UPFC	8-28	43.142	30.079	2.683	2.228
		28-27	35.875	28.822	3.083	3.074
Multi Type	UPFC	8-28	43.142	30.079	2.683	2.228
	SVC	28-27	35.875	28.811	3.083	2.837

Figure 5 represents the variation of power flow for different examples of contingencies with respect to number of iterations of GA as the optimization progresses. Hence the objective of minimizing the flow through the overloaded lines is clearly achieved using GA.

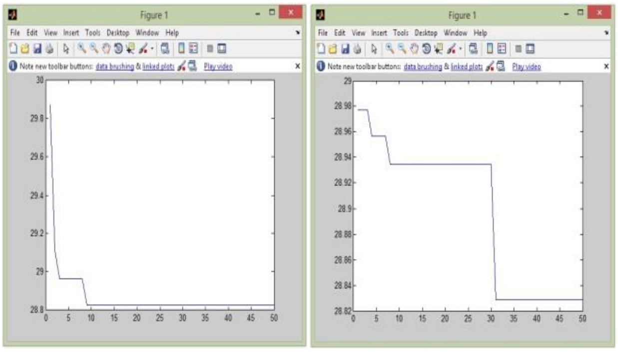

Figure 5.Examples of Power flow variation vs. No.of GA iterations

VI. CONCLUSIONS

By using genetic algorithm, the type of device, location that the device to be placed and suitable compensation value for the device which give the optimum solution for the power flow through over loaded lines could be found out. Hence, the overall transmission line losses could be reduced and also the security of the system can be improved. Hence FACTS devices play a major role in controlling the flow of power in a line. GA proves its promising role in handling Security constrained OPF problems with FACTS devices included.

REFERENCES

1. O.Alsac, B. Scott, "Optimal load flow with steady state security", IEEE Transaction PAS -1973, pp. 745-751. (1973)
2. N. Hingorani, "Flexible AC Transmission," IEEE Spectrum, vol. 30, No.4, pp. 40-45. (1993)
3. S. Rahimzadeh, M. Tavakoli Bina, A. Viki, "Simultaneous application of multi-type FACTS devices to the restructured environment: achieving both optimal number and location," IET Gener. Transm. Distrib., vol. 4, Issue. 3, pp. 349-362. (2009)
4. S.N. Singh, A.K. David, "Optimal Location of FACTS Devices for Congestion Management," ELSEVIER Electric Power Systems Research, vol. 58, pp. 71-79.
5. M. H. Haque, "Optimal Location of Shunt FACTS devices in Long Transmission Lines," IET Gener. Transm. Distrib., vol. 147, Issue. 4, pp. 218-222. (2000)
6. N. K. Sharma, A. Ghosh, R. K. Varma, "A Novel Placement Strategy for FACTS Controllers," IEEE Trans. on Power Delivery, vol. 18, Issue. 3,pp. 982-987. (2003)
7. R .NarmathaBanu, D. Devaraj "Enhanced Genetic Algorithm Approach for Security Constrained Optimal Power Flow Including FACTS Devices", International Journal of Electrical and Electronics Engineering, pp. 552-557. (2009)
8. N. G. Hingorani, L. Gyugyi, Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems, New York: IEEE Press. (1999)
9. D. E. Golderberg, Genetic Algorithm in Search Optimization and Machine Learning, Addison-Wesley Publishing Company, Inc. (1989)
10. S. Verma, S. Saha, and V. Mukherjee, "A novel symbiotic organisms search algorithm for congestion management in deregulated environment," Journal of Experimental & Theoretical Artificial Intelligence, vol. 29, no. 1, pp. 59–79, 2017.

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