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Multi-Type Flexible AC Transmission Systems Devices in Power Systems

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Abstract:

Flexible AC transmission systems (FACTS) devices can effectively optimize the distribution of power flow. Power flow entropy can be applied as a measure of load distribution. In this paper, a method is proposed to optimize the distribution of power flow with the coordination of multi-type FACTS devices and establishes the corresponding mathematical models. The modified group searcher optimization (GSO) algorithm is proposed, in which the angle search is combined with chaotic search model to avoid jumping into local optimization. Compared with the different optimal allocation of multi-FACTS devices, the optimal allocation of multi-FACTS devices is achieved under the economic constraints. The locations obtained by this method can achieve the purpose of balancing power flow and enhancing the system performances. The simulations are demonstrated in an IEEE 118-bus power system with two classical types of FACTS, namely static var compensator (SVC) and thyristor controlled series Compensator (TCSC). The simulation results show that the proposed method is feasible and effective.

Keywords-- ***Chaotic search model, Flexible AC transmission system (FACTS), Group searcher optimization (GSO), Power flow entropy;***

INTRODUCTION

Flexible AC transmission systems (FACTS) devices can make power system more controllable and safe [1]. They can improve the stability of the system and the power transmission capacity and improve the distribution of power flow and reduce the transmission loss through changing the parameters of power transmission system [2–4]. Presently, based on different objective functions, there are many researches on allocation and operations of FACTS with different algorithms, such as genetic algorithm (GA), particle swarm optimization (PSO) or bacterial swarming algorithm (BSA) [5]. Reference [6] studied on minimum singular value index and sensitivity of FACTS controllers to select the optimized location to improve the power transmission capacity. Respectively, the objective functions of minimization of real power loss in transmission lines and voltage deviation at load buses were proposed to identify parameters and locations of FACTS [7, 8]. Considering the vulnerability and network security indices, reference [9] presented a method to improve network security margin by optimizing locations of FACTS devices.

In order to eliminate or alleviate the line overloads, reference [10] presented the method based on the contingency severity index (CSI) described by a real power flow performance index (PI) to determine placement of multi-FACTS devices, and the optimized parameters of FACTS devices could be obtained using GA. Considering the capability characteristics of the SVC and TCPAR, reference [11] analyzed their impacts on composite power system reliability by using evaluation method (EM). To minimize the real power losses and improve voltage profile, a novel bacterial swarming algorithm (BSA) was proposed to select the optimal locations and control parameters of multi-type FACTS devices [12]. Considering different scenarios and using harmony search algorithm (HSA)

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and GA for placement of multi-FACTS devices, reference [13] verified that FACTS devices could improve the power system stability margins, maximum voltage stability margin and reduce losses in the network. The objective functions of maximum system load ability of power system and minimum investment cost were achieved by using GA and PSO, which solved the optimal location and parameter settings of multiple TCSCs problem [14]. Respectively, the effects of FACTS on improving the system load ability and enhancing the TTC value by using GA and evolutionary programming (EP) had been discussed [15, 16]. However, among the above documents, there are few researches related to the aspect of the distribution of power flow.

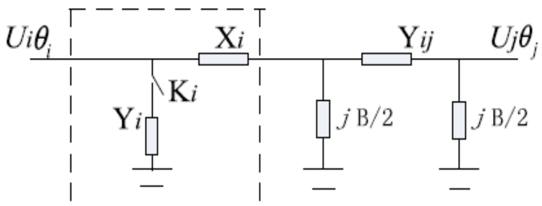

Fig. 1 FACTS model

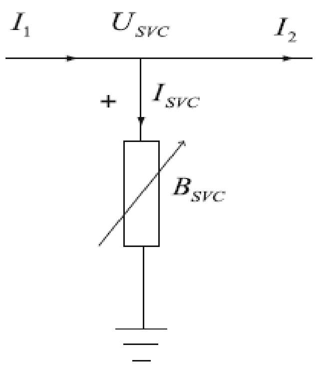

Fig. 2 Equivalent steady-state circuit of SVC

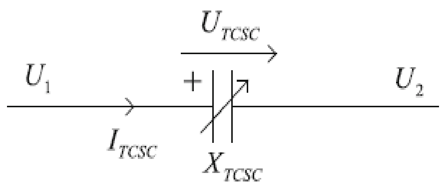

Fig. 3 Equivalent steady-state circuit of TCSC

Based on the entropy theory, a novel concept of power flow entropy has been proposed to measure the distribution of power flow [17]. The smaller the value of power flow entropy is, the more orderly and equal the distribution of power flow will be. The previous studies indicate that homogeneous distribution of power flow, which can improve the security of the system, helps to reduce the probability of cascading failures and large blackouts due to chain reaction in power grids [17–21]. In this paper, the proposed method is for the coordination of multi-type FACTS devices based on power flow entropy. Through the modified GSO algorithm, the optimal locations and control parameters of multi-type FACTS devices are selected and yield efficiency in equalization of distribution of power flow. The proposed method is applied in an IEEE 118-bus power system.

FACTS' MODEL

The steady state models of FACTS devices FACTS devices can be broadly classified into three types, namely shunt, series, and composite series and shunt. When FACTS devices are installed in the transmission system, the model of FACTS devices can be unified as shown in Fig. 1 [22]. Intuitively, FACTS devices affect the system flow distribution mainly through three key parameters, the bus voltage, the line impedance, and the beginning and the end of the relative phase angle. Ki represents a switch here. When the switch Ki is closed, it represents the shunt or composite series and shunt type; when the switch Ki is opened, it represents the series type. In this paper, two classical types of FACTS, SVC and TCSC, are chosen. SVC enhances the power transfer capability of the line by improving the voltage of node, which is paralleled in the system as a variable susceptance as shown in Fig. 2. And TCSC directly involves in modifying the reactance of the line as a capacitive or inductive compensation to improve the power transfer capability of the line as shown in Fig. 3. When SVC and TCSC are incorporated and installed into power system, the node admittance matrix of the system is:

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$$Y' = Y + \begin{bmatrix} 0 & 0 & \cdots & 0 & 0 \\ 0 & \Delta y_{ij} & \cdots & -\Delta y_{ij} & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & -\Delta y_{ij} & \cdots & \Delta y_{ij} & 0 \\ 0 & 0 & \cdots & 0 & 0 \end{bmatrix}$$

where Y and Y0 represent the node admittance matrix of the system before and after the installation of FACTS respectively; i and j represent the nodes installed FACTS devices respectively. In the power flow equations, Jacobian matrix does not change in size. Therefore, in this paper, it only needs to modify the corresponding node admittance of the nodes and branches that have installed FACTS devices, which is conducive to this study.

MODIFIED GSO ALGORITHM AND ITS APPLICATION

Static stability analysis of large complex power systems have many cases. The calculation of addressing arbitration based on traversing method is extremely time-consuming. In this paper, the modified GSO algorithm is adopted for installation location optimization, which can shorten the time of the simulation and obtain the best position.

Table 1 Investment cost per kVar-installed of FACTS

Type of FACTS	Investment cost ($/kVar)
SVC	40
TCSC	50

GSO algorithm:-

Optimization result using the modified GSO algorithm is better than that using the original algorithm. The specific process are:

Step 1: Load the original data of system and FACTS;

Step 2: Generate the initial population of n randomly, and the chaos of the original variables r0;

Step 3: Power flow calculation and data processing. Calculate the objective function value, and select a minimum of objective function as producer in the initial populations. 80 % of the members of the initial population are looked as scroungers, and the rest of the members are looked as rangers;

Step 4: Update the placements of producer, scrounger and ranger, and calculate the objective function value correspondingly using the modified GSO algorithm;

Step 5: If the objective function value is smaller than the objective function value of the initial producer, the new producer replaces the original producer, and the initial producer is merged with scrounger or ranger, continuing to update;

Step 6: Judge the termination condition. If the termination condition (maximum number of iterations) is satisfied, the algorithm is terminated; if not, repeat Step 3 and Step 5;

Step 7: Terminate the algorithm, and output the final optimal producer.

CASE STUDY

To verify the proposed method, the IEEE 118-bus test system is taken into account to select the locations and parameters of multi-FACTS in this paper. This network consists of 54 generator buses and 186 branches [32, 33]. In the modified GSO algorithm, there are 50 initial populations, and the maximum number of iterations is 100. For the purpose of objective optimization, the number of FACTS, line load rate, line flow, and the loss of network are compared. The value of power flow entropy is 9.5208 as the initial accumulator value before installation of FACTS. In this paper, TCSC and SVC were tested respectively.

As shown in Fig. 5, when 15 TCSCs are installed, the value of power flow entropy is more than 9.1875; when 12 SVCs are installed, the value of power flow entropy is more than 9.3740. The comparison clearly shows that the regulatory capacity of TCSC for power flow is better than the regulatory capacity of SVC. However, considering the economic aspect, TCSC

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should be installed into the system in coordination with SVC to achieve optimal value. Through testing, when 4 SVCs and 6 TCSCs are chosen, the value of power flow entropy is 9.1956. Table 4 and Table 5 show that the coordination of multi-FACTS based on power flow entropy has obvious effects on the power system. The corresponding load rates and active power of lines changed at the objective function in Table 4. In fact, the changes of all load rates of lines before and after installation of FACTS devices are shown in Fig. 6. The section above zero level shows that load rates of lines are in positive growth, indicating that load rates of lines increased. The section below zero level shows that load rates of lines are in negative growth, indicating that load rates of lines decreased. Fig. 8 shows active power of lines change before and after installation of FACTS devices.

Types of FACTS	Total investment ($)
12 SVC	304.9×10^4
15 TCSC	376.9×10^4
4 SVC+6 TCSC	331.69×10^4

Table 2 Investment of installation

Types of FACTS	Locations	x_{tcsc}, b_{svc} (p.u.)
SVC1	9	(0, −1)
SVC2	29	(0, −0.30356)
SVC3	84	(0, −0.53839)
SVC4	102	(0, −0.78389)
TCSC5	30–26	(0.04622, 0)
TCSC6	36–34	(0.01441, 0)
TCSC7	66–62	(0.11717, 0)
TCSC8	72–24	(0.10535, 0)
TCSC9	77–76	(0.07955, 0)
TCSC10	80–77	(0.02607, 0)

Table 3 Locations, the reactance and the susceptance of FACTS

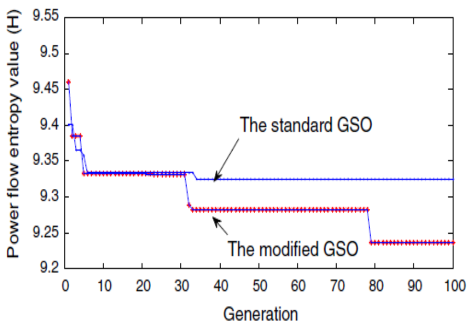

Fig. 4 Comparison of performance index evolution for GSO

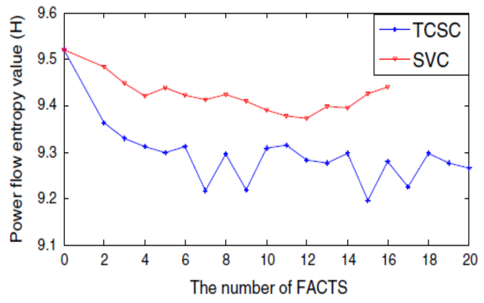

Fig. 5 Curve of entropy value H with the number of FACTS

Number of branches	Without FACTS		With FACTS	
	α_l (p.u.)	P_l (p.u.)	α_l (p.u.)	P_l (p.u.)
21	0.83	1.2327	0.721	1.0709
39	0.435	−0.0365	0.3142	−0.2638
41	0.8962	−1.0934	0.6767	−0.8256
60	0.0169	0.0023	0.2143	−0.0293
96	0.8604	1.9267	0.7774	1.7408

Table 4 Change of load rate and power flow with and without FACTS

FACTS	P (p.u.)	Q (p.u.)	P_{loss} (p.u.)	Q_{loss} (p.u.)
Without FACTS	38.0348	8.1993	1.3548	−5.3372
With FACTS	37.9637	9.7655	1.2837	−3.7934

Table 5 Comparisons of system power generation and loss with and without FACTS

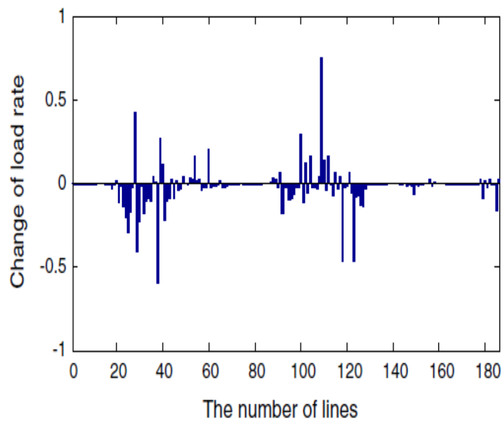

Fig. 6 Load rates changes before and after installation of FACTS devices

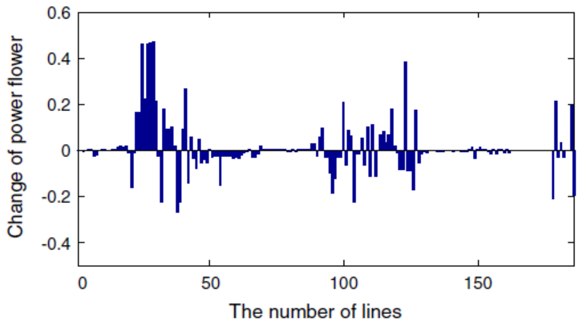

Fig. 7 Power flow changes before and after installation of FACTS devices

The section above zero level shows that active power flow of lines are in positive growth, which means that active power of lines increased. The section below zero level shows that active power flow of lines are in negative growth, which means that active power of lines decreased. By comparing the changes of Fig. 6 and Fig. 7, we know that the active power of line may be negative (positive) before installation of FACTS devices, and the active power of line is likely to become positive (negative) after installation of FACTS devices, which leads to the increase or decrease of the load rate of line. Tables and figures show that the locations based on power flow entropy have obvious effects on power flow of distribution and load rates to achieve power flow optimization in power systems. Under the objective of power flow entropy, the coordination and optimization of multi FACTS decreases the value of power flow entropy to lower the probability of cascading failures and large blackouts due to chain reaction in power grid and improve the security of the system. Meanwhile, it controls the overload lines, improves the low load of transmission power lines, and reduces the active power generations and the losses of power system.

CONCLUSIONS

In this paper, the value of power flow entropy is minimized as an objective optimization function, subject to the power system limits and economic limits. The modified GSO is effectively and successfully implemented to determine optimal allocation of multi-type of FACTS devices. Based on the case study, the following conclusions are:

1) Only the reasonable locations, number and capacities of FACTS can make the distribution of power flow equilibrium. Otherwise they would make the distribution of power flow more uneven and endanger the system security.

2) In this paper, the proposed method can be relatively accurate for allocation of FACTS devices and advantageous to the distribution of power flow.

3) By changing the value of power flow entropy, we can intuitively learn that TCSC has more ability than SVC for power flow regulation.

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