

Optimal Choice and Allocation of FACTS Devices in Deregulated Electricity Market using Genetic Algorithms

Lijun Cai and István Erlich
University of Duisburg-Essen, Germany

Georgios Stamtzis

Yicheng Luo
Hebei Agriculture University, P.R. China

Abstract--This paper deals with the optimal choice and allocation of FACTS devices in multi-machine power systems using genetic algorithm. The objective is to achieve the power system economic generation allocation and dispatch in deregulated electricity market. Using the proposed method, the locations of the FACTS devices, their types and ratings are optimized simultaneously. Different kinds of FACTS devices are simulated in this study: UPFC, TCSC, TCPST, and SVC. Furthermore, their investment costs are also considered. Simulation results validate the capability of this new approach in minimizing the overall system cost function, which includes the investment costs of the FACTS devices and the bid offers of the market participants. The proposed algorithm is an effective and practical method for the choice and allocation of suitable FACTS devices in deregulated electricity market environment.

Index Terms--Allocation, Bid curve, Cost function, Economic generation, FACTS, Genetic algorithms, Pool market, Optimal power flow (OPF).

I Introduction

In recent years, with the deregulation of the electricity market, the traditional concepts and practices of power systems have changed. Better utilization of the existing power system to increase power transfer capability by installing FACTS (Flexible AC Transmission Systems) devices becomes imperative [1, 10].

The parameter and variables of the transmission line, i.e. line impedance, terminal voltages, and voltage angles can be controlled by FACTS devices in a fast and effective way [10,12]. The benefit brought about by FACTS includes improvement of system dynamic behavior and thus enhancement of system reliability. However, their main function is to control power flows [2,4]. Provided that they are placed at optimal locations, FACTS devices are capable of increasing the system loadability too [1]. These aspects are playing an increasingly significant role in the operation and control of the deregulated electricity market.

Many researches were made on the optimal allocation of FACTS devices [1-3]. However, the investment cost of FACTS and their impact on bid curves of the market participants (suppliers and consumers) in liberalized electricity market are not wholly considered [8].

The objective of this paper is to develop an algorithm to find the best locations for the FACTS devices. By means of FACTS optimal placement, the overall cost function, which includes the investment costs of FACTS and the bid offers of the market participants, is minimized.

Different kinds of FACTS devices and their different locations have varying advantages. In realizing the proposed objective, the suitable types of FACTS devices, their location and their ratings must be determined simultaneously. This combinatorial analysis problem is solved using genetic algorithm [1,8,11].

This paper is organized as follows: Following the introduction, different FACTS models are described in section II. Then in section III, the genetic algorithm for the optimal location of FACTS devices is discussed in detail. The simulation results are given in section IV. Finally, brief conclusions are deduced.

II FATS Models

1. FACTS Devices

In this paper, four typical FACTS devices have been selected: TCSC (Thyristor Controlled Series Capacitor), TCPST (Thyristor Controlled Phase Shifting Transformer), UPFC (Unified Power Flow Controller) and SVC (Static Var Compensator). Their functional diagrams are given in Fig. 1.

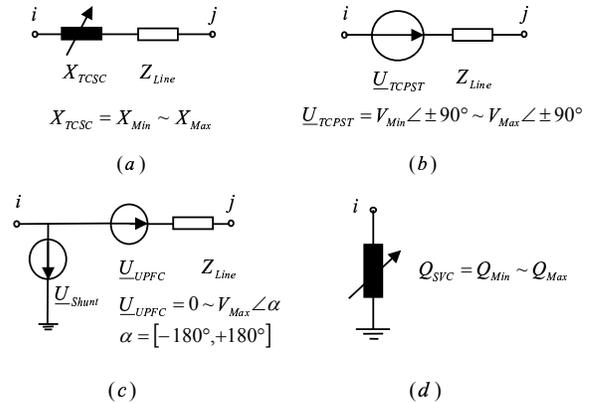


Fig. 1. Functional diagram of the considered FACTS devices (a) TCSC (b) TCPST (c) UPFC (d) SVC

As shown in Fig. 1, the reactance of the line can be changed by TCSC. TCPST varies the phase angle between the two terminal voltages and SVC can be used to control the reactive compensation. The UPFC is the most powerful and versatile FACTS device due to the fact that the line impedance, terminal voltages, and the voltage angle can be controlled by one and the same device [12].

The power flow P_{ij} through the transmission line $i-j$ is a function of the line reactance X_{ij} , the voltage magnitude V_i, V_j and the phase angle between the sending and receiving end voltages $\delta_i - \delta_j$.

$$P_{ij} = \frac{V_i V_j}{X} (\delta_i - \delta_j) \quad (1)$$

The above-mentioned FACTS devices can be used to control the power flow by changing the transmission line parameters so that the power flow can be optimized. Therefore, in multi-machine power systems, optimal utilization of generation units can be achieved by means of FACTS devices.

2. Mathematical Models of FACTS Devices

In this paper, the mathematical models of the FACTS devices are developed mainly to perform the steady-state analysis. Therefore the TCSC is modeled to modify the reactance of the transmission line directly. SVC, TCPST and UPFC are modeled using the power/current injection method [4]. Furthermore, for the TCSC, TCPST and UPFC, their mathematical model is integrated into the model of the transmission line, whereas the SVC model is only incorporated into the sending-end as a shunt element of the transmission line.

The mathematical models of FACTS devices are implemented in *Matpower 2.0* [9]:

TCSC

By modifying the reactance of the transmission line, the TCSC acts as the capacitive or inductive compensation respectively. In this study, the reactance of the transmission line is adjusted by TCSC directly. The rating of TCSC is depend on the reactance of the transmission line where the TCSC is located:

$$X_{ij} = X_{Line} + X_{TCSC}, \quad X_{TCSC} = rt_{csc} \cdot X_{Line} \quad (2)$$

where X_{Line} is the reactance of the transmission line and rt_{csc} is the coefficient which represents the degree of compensation by TCSC.

To avoid overcompensation, the working range of the TCSC is chosen between $-0.7X_{Line}$ and $0.2X_{Line}$ [1,2].

$$rt_{csc_{min}} = -0.7, \quad rt_{csc_{max}} = 0.2$$

TCPST

The voltage angle between the sending and receiving end of the transmission line can be regulated by TCPST. It is modeled as a series compensation voltage $\Delta U_{FACTS} = \Delta U_{TCPST}$, which is perpendicular to the bus voltage. The working range of the TCPST is between -5 degrees to +5 degrees. The injected currents at bus i and bus j can be expressed as follows [14]:

$$\Delta I_{is} = \frac{\Delta U_{TCPST}}{Z_{ij}}, \quad \Delta I_{js} = -\frac{\Delta U_{TCPST}}{Z_{ij}} \quad (3)$$

where Z_{ij} is the total reactance of the transmission line $i-j$.

SVC

The SVC can be operated as both inductive and capacitive compensation. It is modeled as an ideal reactive power injection at bus i :

$$\Delta Q_{is} = Q_{SVC} \quad (4)$$

UPFC

Basically, the UPFC has two voltage source inverters (VSI) sharing a common dc storage capacitor. It is connected to the system through two coupling transformers [6,7,12]. In this study, the series compensation $\Delta U_{FACTS} = \Delta U_{UPFC}$ is employed. The injected currents at bus i and bus j can be expressed as follows:

$$\Delta I_{is} = \frac{\Delta U_{UPFC}}{Z_{ij}}, \quad \Delta I_{js} = -\frac{\Delta U_{UPFC}}{Z_{ij}} \quad (5)$$

III Cost Functions

As mentioned above, the main objective of this paper is to find the optimal locations and types of FACTS devices to minimize the overall cost function consisting of bid offers of the market participants and FACTS devices investment costs.

In this work, a modified version of power simulation software: *Matpower 2.0* is employed [9]. For the intended research, *Matpower* has been extended by incorporating the mathematical models of FACTS devices. Furthermore, cost functions are incorporated for:

- Bids of suppliers and consumers.
- Investment costs of FACTS devices.

1. Bids of the Suppliers and Consumers in Pool Market

Pool market is a basic type of the deregulated power markets. Electricity pools are market institutions designed to permit trade and competition in the supply of energy whilst simultaneously allowing the overall control and coordination of generation and transmission.

The main characteristic of electricity pool market is that the power is traded through the market and not bilaterally between producers and consumers. The market is operated either by a separate *Pool Operator* or directly by the *Independent System Operator* (ISO). The task of market operator is to lead the pool market to a short-run economic optimum [15].

In order to achieve this aim, the market operator collects the electric power bids from suppliers as well as from consumers. These bids are related to a certain time interval. When the bids are submitted, the market operator runs the OPF program taking into consideration the network constraints.

The objective of this OPF program is to minimize the total costs, which is equivalent to maximizing the social welfare. The OPF calculates spot prices for each location (bus) of the grid as well as the quantity of power that is to be supplied or bought by each of the market participant. Consumers and suppliers are then billed to the spot price of their bus for the corresponding amount of power [15]. A schematic description of pool market operation is given by Fig. 2.

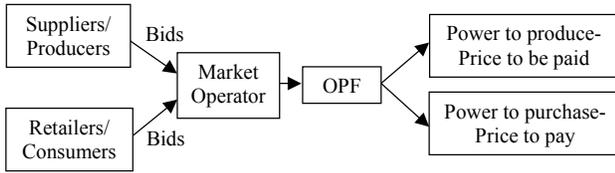


Fig. 2 Electricity pool market

In the monopoly power markets the utility was performing an OPF knowing the real cost data of its generators. Furthermore, the load was also given and had to be fully covered. In the present deregulated market, the pool operator has no knowledge about the cost functions of power plants owned by the producers. Moreover, the wholesale consumers are eligible to vary their demand according to the price that they face. Consequently, the market operator runs the OPF based on the bids collected from the market participants [15].

Typical bid curves for the supplier and consumer are illustrated in Fig. 3. The supply and demand bid curves show the minimum prices to sell and buy a certain quantity of electrical power for the supplier and consumer respectively.

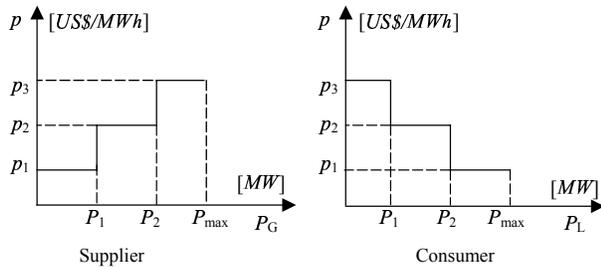


Fig. 3 Supplier and consumer bid curves

2. OPF in Pool Market

In the deregulated pool market, the OPF has the following two functions:

- To minimize the power generation costs.
- At the same to cover the load demands as much as possible.

Therefore the objective function of the OPF can be considered as to maximize the social welfare because the OPF minimizes the global system costs and thereby maximize the profit of all market participants. The objective function is given in (6). For the simplicity, one step bid curves are applied for suppliers and consumers.

$$C_2(\mathbf{P}_G, \mathbf{P}_{UL}) = \mathbf{p}_{\min}^T \mathbf{P}_G + \mathbf{p}_{\max}^T \mathbf{P}_{UL} \quad (6)$$

where

- C_2 : The total generation costs
- \mathbf{P}_G : Generation power
- \mathbf{P}_{UL} : Uncovered load
- \mathbf{p}_{\min} : Minimal acceptable price (bid) of the suppliers
- \mathbf{p}_{\max} : Maximal acceptable price (bid) of the consumers

Certain part of a particular load cannot be covered if the load bid for this part is lower than the suppliers' bid or if system has congestions. In this research, the uncovered load is modeled as a fictitious generator [15]. For the consumer bid curve shown in Fig. 3, the bid curve of fictitious generator can be developed, as shown in Fig. 4.

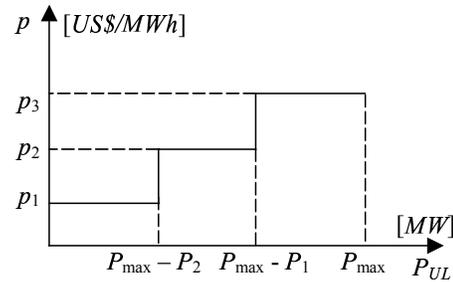


Fig. 4. Bid curve of fictitious consumer generator

A part of fictitious generator is dispatched if the corresponding bid price is lower than the suppliers' bid. It is also possible this generator to be dispatched if system congestions prevent the full cover of the load. For a load located at bus i :

$$\begin{aligned} 0 &\leq P_{ULi} \leq P_{\max i} \\ P_{Li} &= P_{L\max i} - P_{ULi} \end{aligned} \quad (7)$$

where

P_{Li} : covered load portion at bus I
 P_{Lmaxi} : maximum load demand at bus i

Therefore, the above mentioned OPF objective function in the pool market can be now formulated as:

$$C_2(\mathbf{P}_G) = \mathbf{p}_{\min}^T \mathbf{P}_G \quad (8)$$

where the \mathbf{P}_G represents the conventional generators and fictitious generators.

The above mentioned optimization problem can then be solved successfully.

3. FACTS Devices Cost Functions

According to [8,15], the cost functions for SVC, TCSC and UPFC are developed as follows:

UPFC:

$$c_{1UPFC} = 0.0003s^2 - 0.2691s + 188.22(US\$/kVar) \quad (9)$$

TCSC:

$$c_{1TCSC} = 0.0015s^2 - 0.7130s + 153.75(US\$/kVar) \quad (10)$$

SVC:

$$c_{1SVC} = 0.0003s^2 - 0.3051s + 127.38(US\$/kVar) \quad (11)$$

where c_{1UPFC} , c_{1TCSC} and c_{1SVC} are in $US\$/kVar$ and s is the operating range of the FACTS devices in $MVar$.

The cost function for SVC, TCSC and UPFC are shown in Fig. 5.

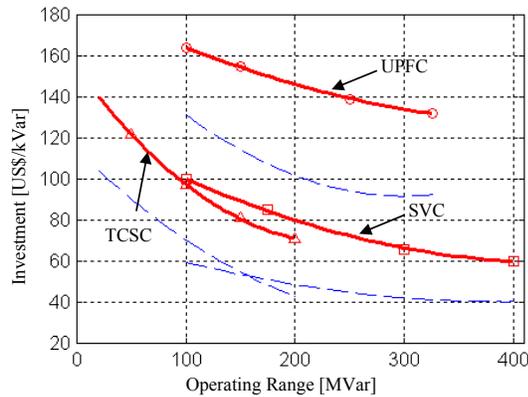


Fig. 5. Cost functions of the FACTS devices: SVC, TCSC and UPFC.

—○— : UPFC. —△— : TCSC. —□— : SVC.
 — : Upper limit: Total investment costs
 - - - : Lower limit: Equipment costs

The cost of a TCPST is more related to the operating voltage and the current rating of the circuit concerned [2,3,5].

Thus, once the TCPST is installed, the cost is fixed and the cost function can be expressed as follows [5]:

$$C_{TCPST} = d \cdot P_{\max} + IC \quad (US\$) \quad (12)$$

where d is a positive constant representing the capital cost and IC is the installation costs of the TCPST. P_{\max} is the thermal limit of the transmission line where TCPST is to be installed [5].

IV Optimal FACTS Allocation

The formulation of the optimal allocation of FACTS devices can be expressed as follows [5]:

$$\begin{aligned} \min. \quad & C_{\text{Total}} = C_1(\mathbf{f}) + C_2(\mathbf{P}_G) \\ \text{s.t.} \quad & \mathbf{E}(\mathbf{f}, \mathbf{g}) = 0 \\ & \mathbf{B}_1(\mathbf{f}) < \mathbf{b}_1, \quad \mathbf{B}_2(\mathbf{g}) < \mathbf{b}_2 \end{aligned} \quad (13)$$

where,

- $C_1(\mathbf{f})$ Average investment costs of FACTS devices.
- $C_2(\mathbf{P}_G)$ Total generation costs defined in (8).
- C_{Total} Overall cost of objective function.
- $\mathbf{E}(\mathbf{f}, \mathbf{g})$ Equality constraints with respect to active and reactive power flow.
- $\mathbf{B}_1(\mathbf{f})$ Inequality constrains for FACTS devices.
- $\mathbf{B}_2(\mathbf{g})$ Inequality constrains for conventional power flow.
- \mathbf{f} Variables of FACTS devices: types, locations and rated values.
- \mathbf{P}_G Generation power of the generators.
- \mathbf{g} Operating state of the power system.

The unit for generation cost is $US\$/Hour$ and for the investment costs of FACTS devices are $US\$/kVar$. They must be unified into $US\$/Hour$. Normally, the FACTS devices will be in-service for many years [10,12]. However, only a part of its lifetime is employed to regulate the power flow. In this paper, five years is applied to evaluate the cost function. Therefore the average value of the investment costs are calculated using the following equation:

$$C_1(\mathbf{f}) = \frac{C^*(\mathbf{f})}{8760 \times 5} \quad (US\$/Hour) \quad (14)$$

where $C^*(\mathbf{f})$ is the total investment costs of FACTS devices.

As mentioned above, power system parameters can be changed using FACTS devices. These different parameters produce different results on the objective function (13). Also, the variation of FACTS locations and FACTS types has also influence on the objective function. Therefore, the conventional continuous optimization methods cannot be successfully applied to find the optimal location of FACTS devices, their types and their ratings simultaneously. To solve this mixed integer problem, the genetic algorithm is employed.

V Genetic Algorithms

Based on the mechanisms of natural selection and genetics, GAs (Genetic Algorithms) are global search techniques. They can search several possible solutions simultaneously and they do not require any prior knowledge or special properties of the objective function [1,8,11]. Moreover, GAs are practical algorithms and easy to be implemented in the power system analysis.

The GAs start with random generation of initial population and then the selection, crossover and mutation are proceeded until the maximal generation is reached.

1. Encoding

The configuration of FACTS devices is encoded by three parameters: the location, type and rated value [1,14]. Each individual is represented by n_{FACTS} number of strings, where n_{FACTS} is the number of FACTS devices needed to be analyzed in the power system, as shown in Fig. 6.

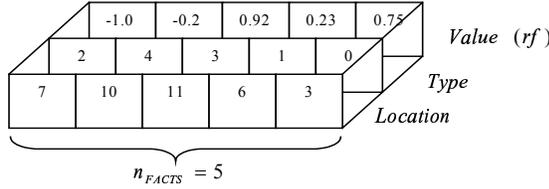


Fig. 6. Individual configuration of FACTS devices.

The first value of each string corresponds to the location information. It is the number of the transmission line where the FACTS is to be located. Each string has a different value of location [1,14]. In other words, it must be ensured that on one transmission line there is only one FACTS device. Moreover, SVC is installed only at one node of the transmission line and the sending node is selected in this study.

The second value represents the types of FACTS devices [1,14]. The values assigned to FACTS devices are: "1" for TCSC; "2" for TCPST; "3" for UPFC and "4" for SVC. Particularly, if there is no FACTS device needed on the transmission line, the value 0 will be employed.

The last value rf represents the rating of each FACTS device. This value varies continuously between -1 and $+1$. The real value of each FACTS device is then converted according to the different FACTS model under the following criterion:

TCSC:

TCSC has a working range between $-0.7X_{Line}$ and $0.2X_{Line}$ [2,3]. The X_{Line} is the reactance of the transmission line where the TCSC to be installed. Therefore rf is converted into the real degree of compensation $rtcsc$ using the following equation:

$$rtcsc = rf \times 0.45 - 0.25 \quad (15)$$

UPFC:

The inserted voltage of UPFC ΔU_{UPFC} has a maximum magnitude of $0.1V_m$, where V_m is the rated voltage of the transmission line where the UPFC is installed. The angle of ΔU_{UPFC} can be varied from -180° to 180° . Therefore rf is converted into the working angle $rupfc$ using the following equation:

$$rupfc = rf \times 180 \text{ (degrees)} \quad (16)$$

TCPST:

The working range of TCPST is between -5° and 5° . Then rf is converted into the real phase shift value $rtcps$ using the following equation:

$$rtcps = rf \times 5 \text{ (degrees)} \quad (17)$$

SVC:

The working range of SVC is between $-100MVar$ and $100MVar$. Then rf is converted into the real compensation value using:

$$rsvc = rf \times 100 \text{ (MVar)} \quad (18)$$

2. Initial Population

The initial population is generated from the following parameters [1,14]:

- n_{FACTS} : Number of FACTS devices to be simulated.
- n_{Type} : FACTS types.
- $n_{Location}$: Possible locations for FACTS devices.
- n_{Ind} : Number of individuals of the population.

First, as shown in Fig. 7, a set of n_{FACTS} numbers of strings are produced. For each string, the first value is randomly chosen from the possible locations $n_{Location}$.

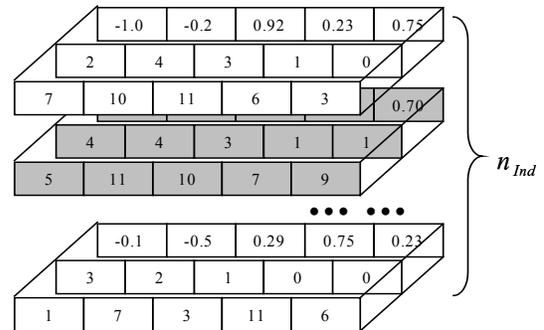


Fig. 7. Calculation of the entire population.

The second value, which represents the types of FACTS devices, is obtained by randomly drawing numbers among the selected devices [1]. Particularly, after the optimization, if

there is no FACTS device necessary for this transmission line, the second value will be set to zero.

The third value of each string, which contains the ratings of the FACTS devices, are randomly selected between -1 and $+1$.

To obtain the entire initial population, the above operations are repeated n_{Ind} times [1]. Fig. 7 shows the calculation of the entire population.

3. Fitness Calculation

After encoding, the objective function (fitness) will be evaluated for each individual of the population. In this work, the fitness is defined as follows:

$$Fitness = m - C_{Total} \quad (19)$$

Because the GAs can only find the maximum positive value of the objective function, a large positive constant m is selected to convert the objective function into a maximum one. In this paper, m is selected as $4000 \text{ US\$/hour}$.

Then reproduction, crossover and mutation are applied successively to generate the offspring.

4. Reproduction

Reproduction is a process where the individual is selected to move to a new generation according to its fitness. The biased roulette wheel selection [1] is employed. The probability of an individual's reproduction is proportional to its part on the biased roulette wheel [11].

5. Crossover

The main objective of crossover is to reorganize the information of two different individuals and produce a new one [1,11]. In this research, as shown in Fig. 8, a two-points crossover [1,14] is applied and the probability pc of the crossover is selected as 0.95 .

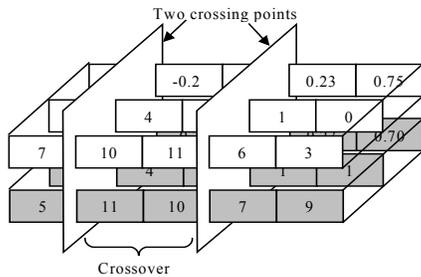


Fig. 8. Two points crossover.

6. Mutation

Mutation is used to introduce some sort of artificial diversification in the population to avoid premature convergence to local optimum [4,11]. Non-uniform mutation, which has proved to be successful in a number of studies [11], is employed in this paper.

The proposed optimization strategy is summarized in Fig. 9. In order to ensure that there is only one FACTS device on each transmission line, the process of "Arrangement of the FACTS locations" is necessary [1,14].

Moreover, in order to achieve a optimized solution, many simulations should be run to ensure the global optimum

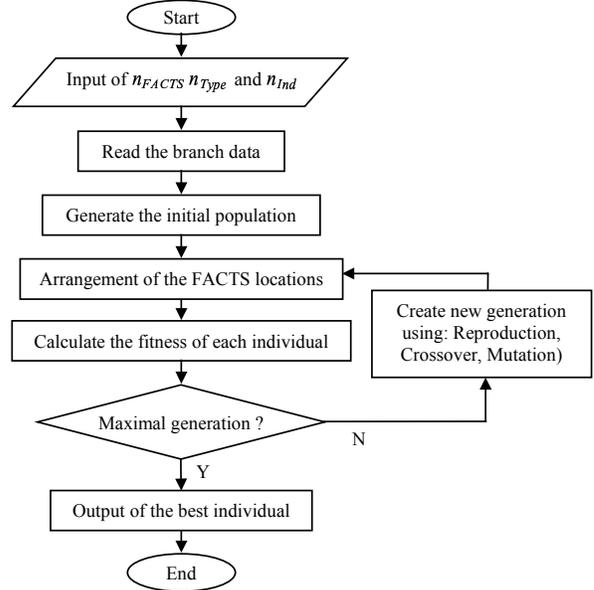


Fig. 9. Flow chart of the GA optimization.

VI Case Study

In order to verify the effectiveness of the proposed method, the 10-bus test system, as illustrated in Fig 10, is simulated. The detailed information about this test system and the bid offers of the market participants are given in Appendix A and B. Different bid curves with operating conditions are simulated for optimal FACTS locations.

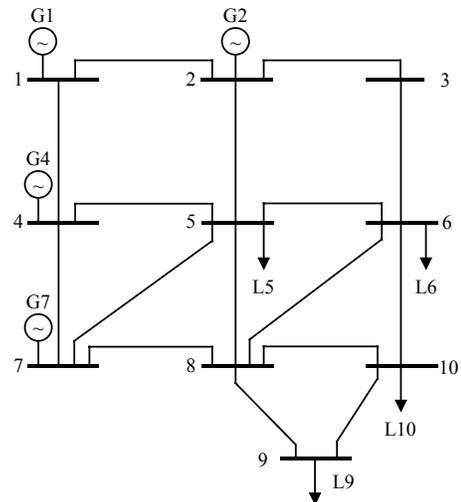


Fig. 10. 10-bus test system

The initial value of n_{FACTS} , which indicates the number of FACTS devices to be simulated, is defined as five. The total number of generation is 200 and there are 20 individuals in each generation. Simulation results of two typical cases are presented in this section.

1. Different Operating Conditions

In this simulation, a typical load curve is simulated. For different time interval, as shown in Table AII, different bid strategies for the generators and loads are applied. For the simplicity, only one day load curve and the correspondent bid curves are simulated. In practice, the extended load curves for the whole year long can be implemented in the simulation. Furthermore, only one step bid curves are examined for the simplification.

The bid offers of the consumer shown in Table AII are chosen relatively high and therefore the loads can be mostly covered.

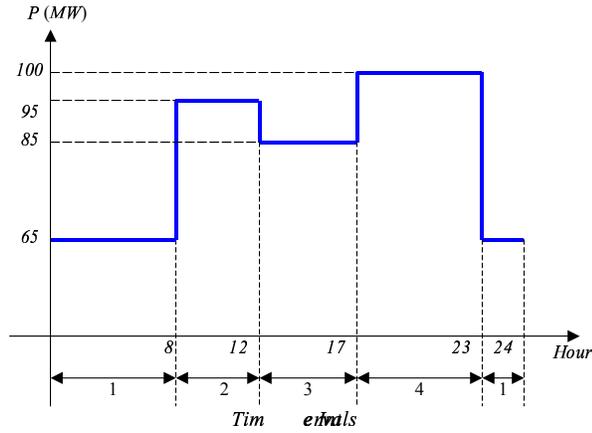


Fig. 11. Typical load curve of a day

With respect to the different load curves, the total generation costs defined in (8) can be calculated as follows:

$$C_2(\mathbf{P}_G) = C_{2-Interval1} \times \frac{T_1}{24} + C_{2-Interval2} \times \frac{T_2}{24} + C_{2-Interval3} \times \frac{T_3}{24} + C_{2-Interval4} \times \frac{T_4}{24} \quad (20)$$

where $C_{2-Interval1} \sim C_{2-Interval4}$ are the generation costs of the different four time interval and $T_1 \sim T_4$ are the duration of the four intervals.

2. Case Study: Power Flow Congestion

In this case, by modifying the maximum transmission capacity of the corresponding transmission lines, the power flow congestion is introduced into transmission lines 2-5, 4-5, 5-8 and 7-8. As can be seen from Table I, the most severe congestion is on the line 4-5. Where μ_{Sr} and μ_{St} are Lagrange multipliers of the sending and receiving end with respect to

inequality constraints of the power flow. S_{Limit} is the maximum transfer capability of the transmission line.

TABLE I
RESULT OF THE ACTIVE POWER FLOW CONGESTION

Line	μ_{Sr1}	μ_{Sr2}	μ_{Sr3}	μ_{Sr4}	μ_{St1}	S_{Limit} (MW)
2-5	-	-	-	-	0.113	120.00
4-5	22.888	81.734	60.856	77.417	21.770	70.00
5-8	1.506	6.420	4.721	6.084	-	65.00
7-8	-	2.347	1.612	2.246	-	94.00

Even though in the algorithm five FACTS devices were considered, according to the GA optimization only one TCSC is required to be installed on the transmission line 4-7 with a compensation level of $-35\% X_{Line}$. Fig. 12 shows the calculation process. The overall system cost, which includes the total generation costs and FACTS investment costs, is 915.90 US\$/hour in this particular test case.

The simulation result shows that for the considered power system, the TCSC is the most efficient solution. Even though UPFC is the most powerful FACTS device, it has not been applied due to its extremely high investment cost.

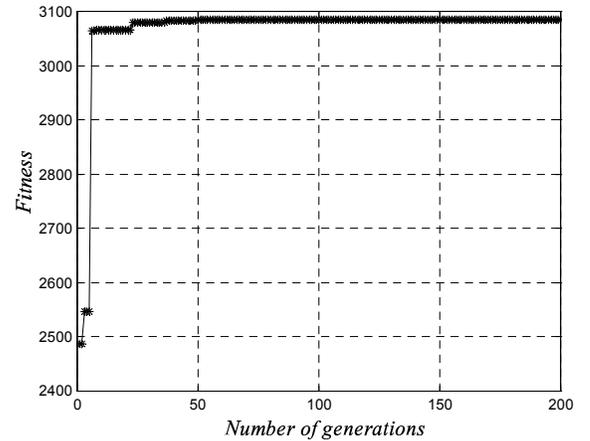


Fig. 12. Simulation result

VII Conclusions

In this paper, a genetic algorithm based approach is proposed to determine the suitable type of FACTS devices and its optimal location in deregulated electricity market. Four typical FACTS devices, i.e. TCSC, UPFC, TCPST and SVC, are simulated. The overall system cost function, which includes the bid offers of the market participants (suppliers and consumers) and the investment costs of FACTS devices, is employed to evaluate the power system performance.

Simulation results validate the efficiency of this new approach in minimizing the overall system cost function. Furthermore, the locations of the FACTS devices, their types and ratings are optimized simultaneously. The proposed algorithm is an effective and practical method for the allocation of FACTS devices in deregulated electricity market.

VIII Appendices

A. Detailed information about the 10-bus test system

TABLE AI
DATA OF THE 10-BUS TEST SYSTEM ($S_B=100$ MVA, $V_B=380$ kV)

From bus	To bus	R		X		b	Capacity [MVA]	From bus	To bus	R		X		b	Capacity [MVA]
		[p.u.] $\times 10^{-3}$	[p.u.] $\times 10^{-3}$	[p.u.] $\times 10^{-3}$	[p.u.] $\times 10^{-3}$					[p.u.] $\times 10^{-3}$	[p.u.] $\times 10^{-3}$				
1	2	3.4	3.60	1.2696	100	5	7	3.4	3.60	1.2696	70				
1	4	3.4	3.60	1.2696	110	5	8	1.7	1.80	0.6348	65				
2	3	3.4	3.60	1.2696	120	6	10	2.4	2.52	0.8888	85				
2	5	3.4	3.60	1.2696	120	6	8	3.4	3.60	1.2696	80				
3	6	3.4	3.60	1.2696	150	7	8	1.7	1.80	0.6348	94				
4	5	3.4	3.60	1.2696	70	8	9	1.7	1.80	0.6348	155				
4	7	2.8	2.88	1.0156	100	8	10	2.8	2.88	1.0156	115				
5	6	2.8	2.88	1.0156	85	9	10	2.4	2.52	0.8888	50				

B. Generation Cost Function

TABLE AII
BID OFFERS OF MARKET PARTICIPANTS

Bus	Art	Bid offers for time interval			
		P_{\max} [MW], p_{\max} [ct/kWh]			
		2 3 - 8 8 - 1	2 1 2 - 7	7 7 - 2 3	
1	Supplier	150, 3	150, 5.4	150, 5.5	150, 4.5
2	Supplier	150, 6	150, 5.4	150, 5.5	150, 4.5
4	Supplier	150, 6	150, 5.4	150, 5.5	150, 4.5
7	Supplier	250, 15	250, 19	250, 18.5	250, 17.5
5	Consumer	100, 20	100, 36	100, 34	100, 30
6	Consumer	100, 20	100, 36	100, 34	100, 30
9	Consumer	100, 20	100, 36	100, 34	100, 30
10	Consumer	100, 20	100, 36	100, 34	100, 30

IX References

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X Biographies



Lijun Cai was born in 1970. He received his B.-Eng., M.-Eng. from Electrical Engineering Department, North China Electrical Power University, P. R. China in 1992 and 1997 respectively. He received his Ph.D in electrical engineering in 2004 from the University of Duisburg-Essen, Germany. His research interests are in the power system dynamics, FACTS optimal location and coordinated control of power oscillation damping controllers.



István Erlich was born in 1953. He received his Dipl.-Ing. degree in electrical engineering from the University of Dresden, Germany in 1976. After his studies, he worked in Hungary in the field of electrical distribution networks. From 1979 to 1991, he joined the Department of Electrical Power Systems of the University of Dresden again, where he received his PhD degree in 1983. In the period of 1991 to 1998, he worked with the consulting company EAB in Berlin and the Fraunhofer-Institute IITB Dresden, respectively. During this time, he had also a teaching assignment at the University of Dresden. Since 1998, he is Professor and head of the Institute of Electrical Power Systems at the University of Duisburg-Essen, Germany. His major scientific interest is focused on power system stability and control, modelling and simulation of power system dynamics including intelligent system applications. He is member of IEEE and VDE.



Technical Chamber of Greece.

Georgios C. Stamtis was born in 1974. He received the Diploma and the Dr.-Ing. degree both in electrical engineering from the Aristotle University of Thessaloniki, Greece, and the University of Duisburg-Essen, Germany, in 1998 and 2003 respectively. His interests are focused in congestion management and transmission pricing in deregulated electricity markets including the application of game theory. He is member of IEEE, VDE and the



Yicheng Luo, was born in 1953, graduated in the department of economy from the Liaoning University. He is now an associated professor in the economic institute of the Hebei Agriculture University. His research interests are economic theory, finance and deregulated electricity markets.