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Multiobjective Fuzzy Optimal Power Dispatch Incorporated TCSC and Load Model[1]

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Abstract: - This paper presents a multi-objective optimal dispatch model based on optimal power flow with the Thyristor Controlled Series Capacitor (TCSC) and load static voltage characteristic. The minimize of the pool purchase cost, pollution emission and active power losses are solved individually in order to define the membership function of objective, then, the multi-objective problem is reformulated into a new standard nonlinear problem by the fuzzy sets theory and max-min operator, finally, it is solved by interior point method and the results that match with multiobjective problem is gained. The effect of TCSC on the optimal dispatch is also investigated in this paper. The test results show that the proposed model more match with the power system operation and can ensure the multi-factor impartiality of Generation Company. The test results also show that incorporation of TCSC can not only utilize the existing lines, but also change the results of optimal dispatch of power system.

Key-Words: - Power system, TCSC, Multiobjective optimal power flow, Fuzzy sets theory, Interior point method

1 Introduction

As open access market principles are applied to power system, power system has changed from the cost based operations to bid based operations. It created competition and trading mechanisms for market participants. There exist four types of participants in the market. They are Independent System Operator (ISO), Generation Company (GenCo), Distribution Company (DisCo) and Transmission Company (TransCo). Under the deregulation environment, market participants in pursuit of maximal profit for themselves. With past and current difficulties in building new transmission lines and the significant increase in power transaction associated with competitive electricity markets, maintaining system security is more than before. An operation point of a power system not only is a stable equilibrium of differential and algebraic equations (DAE), but also must satisfy all the of static constraints at the equilibrium, such as upper and lower bunds of generators, voltage of all bus and transfer capability of all transmission lines. This operation point in power system is solved by Optimal Power Flow (OPF) problem that considering security constraints [1-2]. In other words, OPF is to minimize operating costs of power system, transmission losses or other appropriate objective functions at the specified time instance subject to static equations and inequalities. In addition, the increasing public awareness of the environment protection and the passage of the Clear Air Act Amendments of 1990 have forced the utilities to modify their design or operations strategies to reduce pollution and atmospheric emissions of the thermal power plants. In [3] environmental/economic dispatch (EED) problem is solved by fuzzy sets theory. In [4] EED problem is solved by a strength pareto evolutionary algorithm. In [5], EED problem is solve by fuzzy satisfaction-maximizing approach. However, this approach are not based on OPF, so, system security is not take into consideration. In [6], the authors proposed an multiobjective transaction model incorporated the load static voltage characteristic to minimize for the pool purchase cost and pollution emission , However, it not investigates the effects of TCSC and not considers the active power losses.

The Electric Power Research Institute (EPRI) in the U.S. formalized the broad concept of Flexible AC Transmission System (FACTS) [7] in the late 1980s. The acronym FACTS identifies alternating current transmission systems incorporating power electronics-based controllers to enhance the controllability and increase power transfer capability.

Section II presents the multiobjective optimal

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dispatch model based OPF considering the TCSC and load voltage characteristic, this section also describes the steady operation model of TCSCs. In section III, multiobjectibe optimisation algorithm based fuzzy theory for solving the proposed model is introduced. Section IV presents the results of applying the proposed approach to the test power system. Section V is conclusions.

2 Formualtion of multiobjective OPF incorporating TCSC and load voltage chacteristic

2.1 The Model of TCSC for Power Flow Control

TCSC is a series compensation component. With the firing control of the thyristors, it can change its apparent reactance smoothly and rapidly. There are many papers on the models of TCSC, including the steady state model [7] and the dynamic one [8].

The steady state model we used in this paper is shown in Fig.1.

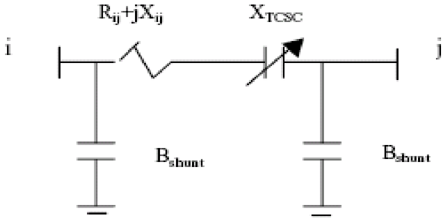

Fig.1. Steady State Model of TCSC

Where, *i* and *j* are the terminal buses of the transmission line *ij*, *X* is the reactance of the line *ij*, *R* is the resistance of the line. In the model, we treat TCSC as a capacitor/inductor whose reactance can vary between –0.5 and 0.5 times the nominal reactance of the branch.

Assume the TCSC is installed the line *ij* and nearby , the corresponding active and reactive power injection as (1) ,(2):

$$P_{ij} = \frac{V_i V_p}{X_{TCSC}} \sin\theta_{ij} \qquad (1)$$
$$Q_{ij} = \frac{V_i}{X_{TCSC}} (V_i - V_j \cos\theta_{ij})$$

$$P_{ij} = \frac{V_p V_i}{X_{TCSC}} \sin\theta_{ji} \qquad (2)$$
$$Q_{ij} = \frac{V_j}{X_{TCSC}} (V_j - V_i \cos\theta_{ji})$$

Where V_i is node voltage of bus *i* , V_j is node voltage of bus *j* , X_{TCSC} is the reactance of TCSC, $\theta_{ij} = \theta_i - \theta_j$ is the phase angle difference of bus *i* and bus *j*.

The active and reactive power balance equations of the corresponding node as (3) ,(4):

$$\Delta P_i = P_{is} - P_{ij} - V_i \sum_{j=1}^{j=n} V_j (G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}) = 0 \quad (3)$$

$$\Delta Q_i = Q_{is} - Q_{ij} - V_i \sum_{j=1}^{j=n} V_j (G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}) = 0 \quad (4)$$

2.2 Objective Function

2.2.1Minimization of Pool Purchase Cost

the total pool purchase cost can be expressed as (5):

$$Min \quad F_1 = \sum_{i=1}^{m} (f(P_{gi})P_{gi}) \qquad (5)$$

Where, $f(P_{gi}) = a_i P_{gi} + b_i$ is the bidding function of generating unit i, P_{gi} is the output of generator unit i , m is the number of total generating unit, respectively.

2.2.2Minimization of Pollution Emission

the atmospheric pollutants such as sulpher oxides SO_x and nitrogen oxides NO_x caused by fossil-fueled thermal units can be model separately. However total ton emission ton can be expressed as (6)

$$Min \quad F_2 = \sum_{i=1}^{m} (\alpha_i P_{gi}^2 + \beta_i P_{gi} + \gamma_i) \qquad (6)$$

Where $\gamma_i, \beta_i, \alpha_i$ are emission characteristics coefficients of generating unit i.

2.2.3 Minimization of Active Power Losses

the total active power losses can be expressed as (7):

$$Min \quad F_3 = \sum_{i=1}^{m} P_{gi} - \sum_{l=1}^{L} P_{Li} \qquad (7)$$

Where $P_{Li} = P_{LiN}(p_{1i}(\frac{V_i}{V_{iN}})^2 + p_{2i}(\frac{V_i}{V_{iN}}) + p_{3i})$, P_{LiN} is the active power demand of bus i , V_{iN} is the rating voltage of bus i ; p_{1i}, p_{2i}, p_{3i} is the coefficients of polynomial or ZIP load model by load modelling Measurement-based or Statistic-based, $p_{1i} + p_{2i} + p_{3i} = 1$.

2.3 Constrains

2.3.1Generation Real Power Limits:

For short-term operation, unit commitment and hydrothermal planning are given to the operating condition. Consequently, any no load and out-out-merit cost considerations that influence the unit commitment are out the scope of this paper.

Therefore the real power output limits of generator i are formulated as:

$$P_{gi\min} \le P_{gi} \le P_{gi\max} \qquad (8)$$

Where $P_{gi\min}, P_{gi\max}$ is the limits of generating unit i.

2.3.2Voltage Control and Reactive Support

Voltage limits refer to the requirement for the system bus voltage to remain within a narrow range of levels, buses feeding load through ULTC transformers that hold the load side voltage within a very band-with, however, buses feeding load through fixed tap transformer is affected by load models. Voltage is affected by reactive power flows. The voltage limits and reactive power output limits can be expressed as (8) and (9), we assumed the power factor of load bus is constant, so reactive power compensation is considered in this paper.

$$Q_{gi\min} \le Q_{gi} \le Q_{gi\max} \qquad (9)$$

$$V_{i\min} \le V_i \le V_{i\max} \qquad (10)$$

Where $Q_{gi}, Q_{gi\min}, Q_{gi\max}$ are stand for reactive output, maximal and minimal reactive limit of generating unit i respectively. $V_i, V_{i\min}, V_{i\max}$ are stand for node voltage, minimal and maximal limits of voltage respectively.

2.3.3 Security Control

Transmission congestion may forced the system operator to buy more expensive generation and pollution instead of cheaper and cleaner alternatives. Kirchoffi's law require that real power and reactive power flows balances at each bus i through the system, in addition, TCSC and ZIP load model is incorporated to the power flow equation, therefore, the aggregate load model of distribution system is considered in OPF.

Real power balance:

$$P_{Gi} - P_{LiN}\left(p_{1i}\left(\frac{V_i}{V_{iN}}\right)^2 + p_{2i}\left(\frac{V_i}{V_{iN}}\right) + p_{3i}\right) - V_i \sum_{j=1}^{j=n} V_j (G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}) = 0 \qquad (11)$$

Reactive power balance:

$$Q_{Gi} - Q_{LiN}\left(q_{1i}\left(\frac{V_i}{V_{iN}}\right)^2 + q_{2i}\left(\frac{V_i}{V_{iN}}\right) + q_{3i}\right) - V_i \sum_{j=1}^{j=n} V_j (G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}) = 0 \qquad (12)$$

Where P_{LiN}, Q_{LiN} is the real reactive power demand of bus i respectively, $Q_{LiN} = P_{LiN} tg\varphi_{iN}$; V_{iN} is the rating voltage of bus i ; $p_{1i}, p_{2i}, p_{3i}, q_{1i}, q_{2i}, q_{3i}$ is the coefficients of ZIP load model by load modeling Measurement-based and Statistic-based, $p_{1i} + p_{2i} + p_{3i} = 1, q_{1i} + q_{2i} + q_{3i} = 1$.

The node bus active and reactive power balance equations of the corresponding TCSC as (3) ,(4)

Transmission constraints:

$$P_{\mathrm{lim}in} \le P_{li} \le P_{\mathrm{lim}ax} \qquad (13)$$

Where $P_{\mathrm{li}} = V_i^2 G_{ij} - V_i V_j (G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}), P_{\mathrm{lim}in}, P_{\mathrm{lim}ax}$ are stand for the real power of transmission line l, limits of transfer capacity of transmission lines l .that is, network congestion are modeled by this constraint.

$$X_{TCSC\min} \le X_{TCSC} \le X_{TCSC\max} \qquad (14)$$

Where $X_{TCSC\min}, X_{TCAC\max}$ is the control limits of TCSC.

3 Algorithm of Multiobjective OPF Incorporating TCSC and Load Voltage Chacteristic

3.1Fuzzy Sets Theory for Multiobjective Optimization Problem

By optimizing the above-formulated objective functions, we will obtain not a single optimal solution, but a set of Pareto optimal solutionswe introduce the membership functions that represent the goals of each objective function as follows:

$$\mu(F_i) = \begin{cases} 1 & F_i \le c_{0i} \\ \dfrac{c_{0i} + \delta_{0i} - F_i}{\delta_{0i}} & c_{0i} < F_i < c_{0i} + \delta_{0i} \\ 0 & F_i \ge c_{0i} + \delta_{0i} \end{cases} \qquad (15)$$

Where F_i is the objective function, c_{0i}, δ_{0i} is the objective function of single-objective optimal and the acceptable objective function value , respectively.

3.2The proposed approach for solving the multiobjective OPF problem

In this section, we introduces an approach that combined the fuzzy sets theory and the interior pint method to solve the multi-objective problem of (5)-(14).

Step1: Solve each single-objective problem using interior point method , respectively. The process can be introduced as follows: solve single-objective for pool purchase cost, that is, the problem is formulated by (5) and (8)-(14), the pool purchase cost C_{01} and bidding results are gained, thus, the emission value

$c_{01}^{'}$ is also can been computation based on (6); the active power losses $C_{01}^{''}$ is also gained based on (7), we solve smultiobjective OPF model for minimization of emission, the problem can be model by (6) and (8)-(14), the emission c_{02} and bidding results are also get, thus, the pool purchase cost objective value $c_{02}^{'}$, the active power lossess $C_{02}^{''}$ are gained. In the same way, we solve smultiobjective OPF model for minimization of active power lossess, the problem can be model by (7) and (8)-(14), the active power losses C_{03} and bidding results are also get, thus, the pool purchase cost objective value $C_{03}^{'}$, the pollution emission $C_{03}^{''}$ are gained.

Step-2: Define membership function for each objective. Because of pool purchase cost , emission and active power losses are all cost type index, that is, the smaller of objective value, the better of results of operation planning. therefore, we let $F_1(p_{gi}) \le c_{01} + \delta_{01}$ represents an imprecise upper bound on the maximum permissible pool purchase cost. δ_{01} is the “tolerance” parameter that is a measure of fuzziness in this constraints, it is very important to multi-objective optimal results, $\delta_{01} \le \max\{C_{02}^{'}, C_{03}^{'}\} - C_{01}$ .So we can use the following mathematical formulation for this membership function:

$$\mu(F_1) = \begin{cases} 1 & F_1 \le c_{01} \\ \dfrac{c_{01} + \delta_{01} - F_1}{\delta_{01}} & c_{01} < F_1 < c_{01} + \delta_{01} \\ 0 & F_1 \ge c_{01} + \delta_{01} \end{cases} \tag{16}$$

in the same way, we let $F_1(p_{gi}) \le c_{02} + \delta_{02}$ represents an imprecise upper bound on the maximum permissible emission. δ_{02} is the “tolerance” parameter that is a measure of fuzziness in this constraints, $\delta_{02} \le \max\{C_{01}^{'}, C_{03}^{''}\} - C_{02}$ .So we can define a linear membership function as follows:

$$\mu(F_2) = \begin{cases} 1 & F_2 \le c_{02} \\ \dfrac{c_{02} + \delta_{02} - F_2}{\delta_{02}} & c_{02} < F_2 < c_{02} + \delta_{02} \\ 0 & F_2 \ge c_{02} + \delta_{02} \end{cases} \tag{17}$$

we let $F_3 \le c_{03} + \delta_{03}$ represents an imprecise upper bound on the maximum permissible emission. δ_{03} is the “tolerance” parameter that is a measure of fuzziness in this constraints, $\delta_{03} \le \max\{C_{01}^{''}, C_{02}^{''}\} - C_{03}$ .So we can define a linear membership function as follows:

$$\mu(F_3) = \begin{cases} 1 & F_3 \le c_{03} \\ \dfrac{c_{03} + \delta_{03} - F_3}{\delta_{03}} & c_{03} < F_3 < c_{03} + \delta_{03} \\ 0 & F_3 \ge c_{03} + \delta_{03} \end{cases} \tag{18}$$

STEP3: Build a fuzzy multiobjective optimization operation planning model based on the fuzzy set theory and max-min operator, this problem can be formulated as follows:

Objective function: $\min -\mu$ (19)

Subjective to:

$$\sum_{i=1}^{m} (f(P_{gi})P_{gi}) + \delta_{01}\mu \le \max\{C_{02}^{'}, C_{03}^{'}\} \tag{20}$$

$$\sum_{i=1}^{m} \alpha_i + \beta_i p_{gi} + \gamma_i p_{gi}^2 + \delta_{02}\mu \le \max\{C_{01}^{'}, C_{03}^{''}\} \tag{21}$$

$$(\sum_{i=1}^{m} P_{gi} - \sum_{l=1}^{L} P_{Li}) + \delta_{03}\mu \le \max\{C_{01}^{''}, C_{02}^{''}\} \tag{22}$$

$$0 \le \mu \le 1 \tag{23}$$

(3),(4),(8)-(15)

Step4: Use the interior point method to solve the new single-objective model for maximize membership degree is built by step3, thus, the bidding results that match with the three objectives are gained.

4 Example Analysis

In this paper, a 5-bus 2-generator test system is used to simulation. The single-line diagram of power system and parameters are given in [6], TCSC is installed line between node 4 , 5 and nearby the node 4, the parameters of TCSC are given in [8].The value of bidding price and emission coefficients are given in Table 1 The parameters of load demand and ZIP load model coefficients are given in Table2.

Table1 Generator bidding price and emission confficients

		G1	G2
Cost	a	0.00212	0.00135
	b	1.8015	1.1285
Emission	α	4.285	4.0961
	β	-5.0940	-5.5540
	γ	3.380	6.4960

Table 2 Paramters of load demand and coefficents of ZIP load modelL

Bus	P_{LiN}	Q_{LiN}	P_{1i}	P_{2i}	P_{3i}	Q_{1i}	Q_{2i}	Q_{3i}
2	0.50	0.20	0.63	0.17	0.20	0.80	0.12	0.08
3	0.50	0.32	0.74	0.15	0.11	0.37	0.20	0.43
4	0.45	0.20	0.83	0.11	0.06	0.41	0.30	0.29
5	0.40	0.21	0.20	0.50	0.30	0.30	0.23	0.47

In the simulation results, Table3 shows the comparison of objective function values by single /multi objective optimization with or without TCSC;

Table 3 Comparsion of objective values by single/multi objective optimization with/without TCSC

		Active power losses	Pool purchase cost	Pollution emission
Minimize of active power losses	With TCSC	0.0368	2.4832	11.6022
	Without TCSC	0.0348	2.4849	11.6203
Minimize of pool purchase cost	With TCSC	0.0534	2.4569	11.3124
	Without TCSC	0.0588	2.4571	11.3117
Minimize of pollution emission	With TCSC	0.0632	2.9363	6.3257
	Without TCSC	0.0652	2.9402	6.3361
Multi-objective optimization	With TCSC	0.0453	2.6121	8.7095
	Without TCSC	0.0464	2.6407	8.4353

Table 4 Comparsion of bidding of bidding results by single/multi objective optimization with/without TCSC

		P1	P2	Q1	Q2
Minimize of active power losses	With TCSC	0.5	1.3995	0.4356	0.8622
	Without TCSC	0.5	1.4009	0.2863	0.7514
Minimize of pool purchase cost	With TCSC	0.5	1.3763	1.4	-0.1143
	Without TCSC	0.5	1.3762	1.4	-0.3261
Minimize of pollution emission	With TCSC	1.2096	0.6678	1.4	-0.0967
	Without TCSC	1.2907	0.6710	1.2213	-0.1297
Multi -objective optimal	With TCSC	0.7234	1.1572	1.0285	0.2526
	out TCSC	69	80	74	24

From Table 3 and Table 4, Results of objective values and bidding results are difference between with and without TCSC in multi-objective optimal power flow dispatch model.

5 Conclusions

This paper presents a multi-objective optimal dispatch model with the Thyristor Controlled Series Capacitor (TCSC) and load static voltage characteristic. The proposed model is formulated as multi-objective optimal power flow (MOPF) problem with competing pool purchase cost, pollution emission and active power losses impact objectives. The minimize of the pool purchase cost, pollution emission and active power losses are solved individually in order to define the membership function of objective, then, the multi-objective problem is reformulated into a new standard nonlinear problem by the fuzzy sets theory and max-min operator, finally, it is solved by interior point method and the results that match with multi-objective problem is gained. The effect of TCSC on the optimal dispatch is also investigated in this paper. The test results show that the proposed model more match with the power system operation. The test results also show that incorporation of TCSC can not only utilize the existing lines, but also change the results of optimal dispatch of power system.

In conclusion, the proposal model in this paper can make environmental, economic and active power losses are multi-objective optimization. Moreover, the proposed model base fuzzy set theory in this paper takes the economic, environmental network site characteristic of Generation Company into account, therefore , the proposed model can ensure the multi-factors impartiality of Generation Company.

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