

# Research on congestion elimination method of circuit overload and transmission congestion in the internet of things

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**Abstract** Power system is facing new challenges and opportunities in the environment of the internet of things. Under the circumstance of Internet of things, the transmission congestion management of interruptible load is the important measure to improve system reliability and operating economy. Considering the condition of target selected under different circumstances, this paper proposes a new multi-objective model of transmission congestion management with interruptible load based on brand circuit overload match with interrupt capacity. The multi-object model puts forward three goals, brand circuit overload match with interruptible load, the minimum number of interruptible load nodes and the minimum total interruption of interruptible load. Against other optimization methods can not prioritize to multiple targets and it can easily lead to convergence in the process of solving problems, the paper presents construct evaluation function based on the linear weighted sum to optimize multi-objective linear problem. This method can be sorted prior to multi-objective optimization model. And it has better convergence than other optimization methods in the solution process. Finally, it tests and verifies the correctness of method through the IEEE 30 bus power system. And it successfully applied to grid congestion management in oil.

**Keywords** Transmission Congestion · The Internet of things · OPF · Branch Circuit Overload Capacity · Interrupt amount

## 1 Introduction

The rise of the Internet of things, make the power system has to face many new problems. As at the beginning the rise of the Internet, and the problems faced in today's power system also

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need to face more and more serious transmission congestion problem. With the opening up of the grid and cross-regional electrical energy trade increasing, the deepening of power market reform, it is necessary to carry out a wider range of optimal allocation of resources. The gradual opening of demand side has become an important part of congestion management [3]. The increasing of electricity trade and power flow uncertainty has limited the transmission of electrical energy obviously. Consequently, transmission congestion had become an important subject to be solved.

The transmission congestion of power system means that the requirements of power transmission can't be satisfied because of the limitation of its transmission capacity, which usually includes transmission lines or transformer active power flow exceeding the permitted limit and the node voltage off-limit, etc. In order to eliminate the congestion, the management mode of congestion presents diversification. In the traditional congestion management mode, power grid companies adjust power plant power plan, and generator outputs to invoke a high power. This kind of congestion management usually concentrates on the side of power generation. Literature [17] proposes a congestion management model of joint mode; its essence is to consider all kinds of security constraints of the Optimal Power Flow (OPF) problems. Due to the fluctuation of node electricity price under this model is very big, and trade surpluses can be produced, which produce wrongful stimulate to the Independent System Operator (ISO). Therefore the PJM energy market in the United States and electricity market in the New England use financial transmission rights to solve the transmission congestion [2, 11]. User demand elasticity is also used to solve the transmission congestion. Under the market structure of both sides of supply and demand quoting at the same time, the load of each node is a decision variables affected by price, ISO can control electricity to ease congestion flexibly. Literature [5] structures congestion management model with the method of sensitivity analysis. Literature [1] uses generator rescheduling to solve the congestion, and provides a kind of congestion cost allocation method.

Using IL (Interruptible Load) to solve the congestion management is a new solution of the congestion management in recent years. IL can make full use of the electricity elasticity, eliminate or relieve congestion and the power supply tension in peak load. According to the interruptible power supply contract signed by the power company and power users [10], it allows power companies to remove part of the user load as the contracted purview at a particular period of time (such as peak load). Meanwhile giving the user certain power shortage compensation can reduce the electricity load during peak hours to relieve the tense situation of power supply, thus achieve the purpose of congestion management.

## 2 The calculation of the maximum transmission capacity based on OPF

The reason of transmission congestion appearing in the power system is the limit of the heat capacity of transmission line and the stability of the system. So, in the electricity market, in order to guarantee to make full use of the transmission capacity and not appear line congestion phenomenon, studying and calculating transmission capacities are indispensable links. At present, the method for calculating the maximum transmission capability mainly includes three [8]: the calculation method based on power transmission distribution factor, continuous power flow calculation method, the OPF calculation

method. The OPF calculation method is calculating the maximum load capacity in the constraint condition of equality and inequality, including the power flow equation and transmission line heat constraints, etc. Compared with the other two methods, it can optimize the allocation of resources, calculate the maximum transmission capacity more accurately, and the calculation results are not too conservative.

## 2.1 Mathematical model

Determining the maximum transmission capacity is increasing transmission and reception respectively at a given power generation node(s) and the load node(s), then solving power flow equations and checking whether there is an overload line or out of node voltage out-of-limit, repeating the process until appearing the overload line or out-of-limit node. Therefore, the mathematical model is as follows:

$$\begin{aligned} & \max \lambda_d \\ & \text{s.t. } g(x, \lambda_d) = 0 \\ & h(x) \leq 0 \end{aligned} \quad (1)$$

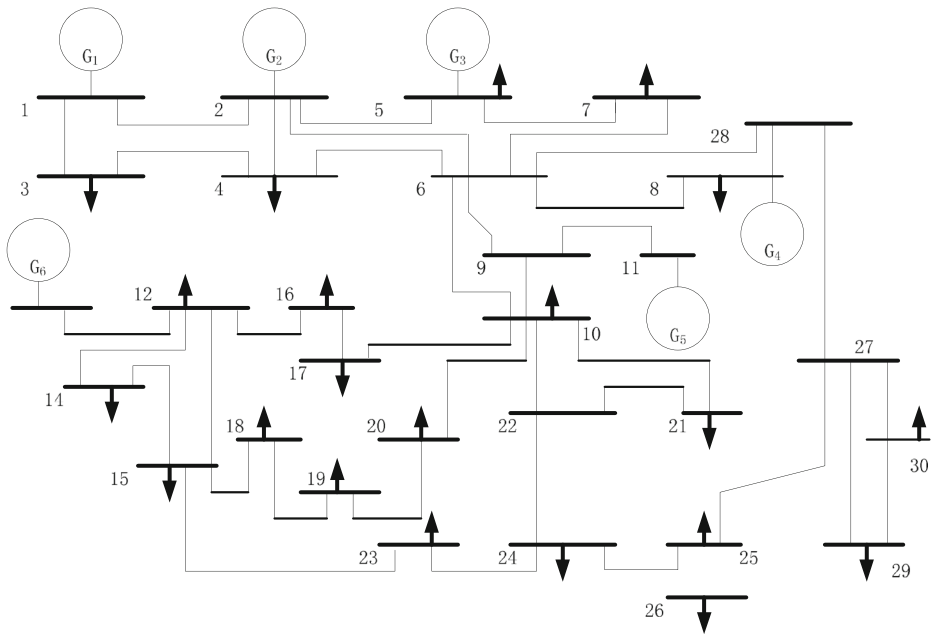
Where  $\lambda_d$  is a real parameter variable, reflecting the system transmission capacity of the node load and generator power in a given varying modes.  $g(x, \lambda_d) = g(x) + \lambda_d b_d$ ,  $b_d$  injects the varying direction vector for system nodes power. When  $\lambda_d$  changes, it only decides the changes of the node load in the reception area. The mathematical model can achieve the generator optimum scheduling of power transmission area, while taking into account the changes of the node load in the reception area to make the calculated result be consistent with the actual situation but also more accurate.

## 2.2 Calculation process and result

IEEE-30 bus system is calculated with the method based on the trust region interior point method for the above mathematical model. Branches connection of the system is shown in Fig. 1, a total of 6 generators, 37 branches.

The OPF algorithm based on trust region interior point method is implemented by C++ language, compiled in Visual C++ 6.0 environment. Using this algorithm, IEEE-30 bus system is simulated and calculated. The basic parameters of the system are as follows: 6 generators, 37 branches, active load 2.8340 MW, reactive load 1.2620MVAR, initial net loss 7.09 MW, the objective function is the system node load. Relevant parameters of the algorithm is set to: the initial trust region radius  $\Delta_0 = 0.4$ , penalty parameter  $\sigma = 10.0$ , related parameters of adjusting the trust region radius of  $\rho_1 = 0.5$ ,  $\rho_2 = 0.6$ ,  $\rho_3 = 0.8$ , convergence criterion  $\varepsilon = 0.01$ , convergence criterion of LP sub-problems  $\varepsilon_{LP} \leq 0.001$ . The results are shown in Tables 1 and 2 below.

The results can be seen by using OPF method can accurately calculate the maximum transmission capacity of the branch, thus determine the out-of-limit branch, and lay the foundation of using interruptible load to eliminate congestion.



**Fig. 1** IEEE 30 bus system

### 3 The transmission congestion management model based on branch load

Having determined the branch appearing transmission congestion, it is necessary to eliminate the branch circuit congestion. Bringing the interruptible load into transmission congestion management, the most important thing is to select interruptible load. And different objective condition, the selection scheme is different. Literatures [6, 9] targeted the minimum purchasing cost. Considering taking interruptible load as reserve capacity of a system and the impact of price fluctuations on the power company, literature [9] established the purchasing model of the optimal accident interruptible load based on risk and used a computerized random simulation method to solve complex problems with uncertainty, then finished solving the single objective function. Literature [6] took outage duration and the total number of power outage as constraints. The objective function was flow calculated to obtain the optimal solution. Literatures [7, 15] regarded the minimum power purchasing cost as the objective function of congestion scheduling. Comparing the traditional congestion scheduling model with the mathematical model using interruptible load for congestion scheduling from the perspective of power purchasing cost, combining of congestion amount of congestion lines, and calculating with OPF, illustrated that using interruptible load to congestion scheduling can save power purchasing costs effectively.

**Table 1** Results of power node in zone 2 and load node in zone 1(MW)

Node	13	23	2	3	4	7	8
Result	35.04	30.81	37.31	4.13	13.07	39.20	51.58

**Table 2** Calculation results of maximum transmission capacity from power node to load node

	Active Power	Active Node	Power Flow Out-of-limit Branch
Calculation Result	65.85	167.05	6–8,21–22,23–24

### 3.1 The establishment of the mathematical model

This paper divides congestion eliminating scheme into three different cases, sorting matching capacity, interruptible capacity and choosing amount respectively, to eliminate congestion by choosing interruptible load reasonably.

- (1) In the cases of load amount of interruptible load contracts signed not identical and matching with the branch circuit overload, interruptible load matching with load amount should be selected. Model representation is as follows:

$$\min f_1 = P_i, i = 1, 2, \dots, N_1 \quad (2)$$

In the formula,  $P_i$  indicates the  $i$ -th load amount matching with the overload.

- (2) In the cases of multiple identical capacity interruptible loads and these load capacity matching with branch circuit load, interrupt node should be selected as little as possible, meaning to select the minimum interrupt amount of interruptible load users at the same time. Shown as follow:

$$\min f_2(P_i) = \min \sum_i^{N_i} P_i(K_i), i = 1, 2, \dots, N_1 \quad (3)$$

In the formula,  $N_i$  is the number of users interruptible load.  $K_i$  is 0–1 variable representing the selection of interruptible load.  $K_i = 1$  denotes choosing the  $i$ -th interruptible load user.  $K_i = 0$  indicates the user is not selected.

- (3) On the condition that no load capacity in all contracts signed interruptible load matching with branch circuit load, the load reduction should not increase the burden on the ISO. Hope that under a certain amount of compensation, the total load reductions as few as possible to eliminate the congestion, i.e., according to select the least interruptible load amount of the scheme as objective function, model representation is as follows:

$$\min f_3(\Delta P_{di}) = \min \sum_i^{N_1} \Delta P_{di} \quad (4)$$

In the formula,  $\Delta P_{di}$  is the load amount of the  $i$ -th interruptible user reduced in the congestion management.

### 3.2 The constraints

The constraints of the mathematical model presented in this paper can be represented as inequality, including load interruption amount constraint, branch transmission capacity constraint, generating capacity constraint, the system reserve capacity constraint [14], etc. They are represented separately by the following formula:

- (1) Load interruption amount constraint

$$\Delta P_{di} \leq \Delta P_{di}^{\max} \quad (5)$$

The above formula indicates that the interrupt load amount on IOS reduced at node  $i$  can not exceed the largest interruptible load amount reported by the interruptible load users at this node.

- (2) Branch transmission capacity constrain

$$P_{ij} \leq P_{ij}^{\max} \quad (6)$$

The above formula denotes that branch power flow in operation can not exceed the maximum value of each branch.

- (3) Generating capacity constraint

$$P_{gi}^{\min} \leq P_{gi} \leq P_{gi}^{\max} \quad i \in [1, 2, \dots, N_g] \quad (7)$$

In the formula,  $P_{gi}^{\min}$ ,  $P_{gi}^{\max}$  are separately the upper and lower limit value of active power output of the node  $i$  generator.

- (4) Operating reserve capacity constraint

$$\sum_i^{N_g} P_{gi}^{\max} \cdot T_i - \sum_i^N P_{di} + \sum_i^{N_1} \Delta P_{di} \geq R \quad (8)$$

The above formula indicates that capacity margin of power system operating environment. To ensure system reliability, the value can not less than the minimum value  $R$ ; The value is generally 5 % of the total system load.  $T_i$  is 0–1 variable, which represents if generator generates.  $N_g$  is total number generators,  $P_{gi}^{\max}$  is the maximum active power output of the node  $i$  generator.

### 4 The solution to objective model based on constructing evaluation function method

The mathematical model given by this paper is a multi-objective linear programming problem. There are many kinds of solving methods for this model. The satisfaction of different nature of the conflicting multiple objectives of should be considered at the same time. In the

comprehensive consideration of various objective conditions, we should seek a suitable optimization scheme, and make every objective be in a better state as much as possible. The traditional multi-objective optimization methods are the following [4]: 1. goal programming method, 2. fuzzy optimization method, 3. interactive programming method, 4. layered solution method.

In view of the traditional multi-objective optimization method can not prioritize the existing objective conditions shortcomings, this paper uses constructing evaluation function method to handle multi-objective function model in this paper, which in order to solve the selection scheme of interruptible load. Constructing evaluation function method is to construct an evaluation function, and its essence is transforming the multi-objective model into a single objective model by evaluation function constructed, and solving the single objective function transformed. The method of constructing evaluation function has three basic methods for solving. This paper uses the constructing evaluation function method based on linear weighted sum to optimize the mathematical model.

Linear weighted sum method is to give the corresponding weights according to the degree of importance of each sub-goal; and then the sub-goals are multiplied by their respective weights, adding together again. When using this method to construct the evaluation function, the units of each sub-goal have been away from the concept of independence. Weights (weighting factor) size represents the importance of the corresponding objective function in the optimization model, the more important goal, the greater the weights. The method is based on the decision maker's preferences of each objective function to give each goal certain weights. It is expressed as follows:

$$\min \lambda^T f(x) = \sum_{j=1}^m \lambda_j f_j(x) \quad (9)$$

In the formula,  $f(x) = (f_1(x), \dots, f_m(x))^T$ ,  $\lambda = (\lambda_1, \dots, \lambda_m)$ .  $\lambda_1, \dots, \lambda_m$  is a set of weight coefficients, reflecting a preference of decision makers. The weight coefficients change in a certain range, so as to get effective solution set.

This paper has three objective functions, in accordance with the matching degree between overload capacity and interruptible load to construct a mathematical model by using linear weighted sum method, which is expressed as follows:

$$F(X) = \sum_{i=1}^L \omega_i f_i(x), X = (x_1, x_2, \dots, x_n)^T \quad (10)$$

In the formula,  $f_i(x)$  is each objective function;  $\omega_i$  is a set of weight coefficients.

Evaluation function constructed by using the linear weighted sum method is shown as follows:

$$F = \omega_1 f_1 + \omega_2 f_2 + \omega_3 f_3 \quad (11)$$

Namely:

$$F = \omega_1 P_i + \omega_2 (K_1 + K_2 + \dots + K_{N_1}) + \omega_3 \Delta P \quad (12)$$

Solving the optimal solution of this kind of evaluation function has the following theorems:

Setting  $X^* \in D$  ( $D$  is feasible region), if for any  $X \in D, f_i(X^*) \leq f_i(X)$  ( $i = 1, 2, \dots, n$ ) sets up all the time, then calling  $X^*$  as absolute optimal solution for the objective function, the optimal solution for short.

In general, the objective function which decision makers prefer relatively, its weight coefficient should be given a larger value (in principle value is less than equal to 1). And in the second important objective function, its corresponding weight coefficient should be small (or even 0). In the method of determining the weight coefficient,  $\alpha$  method is a more popular method [12]. It is mainly according to  $m$  sub-goal minimum point information, introducing an auxiliary parameter  $\alpha$ , to list  $m + 1$  order equations, and then solving it to get sub-goal weight coefficient.

Specifically, corresponding model  $VMP$ , it is set feasible region as  $X$ , each objective function  $f_j(x)$ , set the minimum point  $x^j$  in the feasible region:

$$f_j(x^j) = \min_{x \in X} f_j(x), j = 1, 2, \dots, m \tag{13}$$

Using  $x^j$  can calculate  $m^2$  target value, namely

$$f_{ij} = f_j(x^i), i, j = 1, 2, \dots, m \tag{14}$$

Introducing auxiliary parameter  $\alpha$ , to list  $m + 1$  order equations of  $\omega_i (i = 1, 2, \dots, m)$  and  $\alpha$  in (13)

$$\begin{cases} \sum_{i=1}^m f_{ij} \omega_i = \alpha, j = 1, 2, \dots, m \\ \sum_{i=1}^m \omega_i = 1 \end{cases} \tag{15}$$

Set the coefficient matrix (14) of the top  $m$  linear equations in (13) invertible:

$$(f_{ij}) = \begin{pmatrix} f_{11} & \cdots & f_{m1} \\ \cdots & \cdots & \cdots \\ f_{1m} & \cdots & f_{mm} \end{pmatrix} \tag{16}$$

The unique solution of (3–34) can be obtained

$$\begin{cases} (\omega_1, \omega_2, \dots, \omega_m)^T = \frac{e^T (f_{ij})^{-1}}{e^T (f_{ij})^{-1} e} \\ \alpha = \frac{1}{e^T (f_{ij})^{-1} e} \end{cases} \tag{17}$$

In the formula,  $e = (1, 2, \dots, m)^T$  is an  $m$ -d vector,  $(f_{ij})^{-1}$  is the inverse matrix of  $(f_{ij})$ . Each  $\omega_i (i = 1, 2, \dots, m)$  in (17) is a set of weight coefficient solved.

After determining the weight coefficient, then the evaluation function in multi-objective programming problem can be transformed into a simple single objective problem, which can be solved by an improved simple line available method [16].



## 5 Validation of the IEEE30 node system

This paper takes IEEE-30 node system as an example to simulate, each node load parameter is shown in Table 3 [13].

Assuming that the user is rational, who can report interruptible load according to the amount of power shortage. The nodes where users participating in congestion management and interruptible load amount of users are shown in Table 4.

Overload branch circuit and overload capacity of the system are determined in three different cases by power flow calculation. As shown in Table 5, three cases were: in normal operating condition, the transmission lines appear congestion; generator G6 unexpectedly power outage, transmission lines appear congestion; the overloaded branches of 1–3 nodes disconnect, transmission lines appear congestion.

### 5.1 The relief of the line congestion in the normal operation

In this paper, in verifying to IEEE-30 system, it should first consider the optimizing situation of single objective (brand circuit overload match with interruptible load, the minimum number of total interrupt amount and the minimum number of interruptible load users), and calculate the case of optimizing multi-objective composed three single objective as the objective function to get selection scheme of interruptible load based on constructing evaluation function. Interruption scheme obtained by calculation and analysis are shown in Table 6; and then analyzing calculation result by comparison to obtain Table 7.

From the results can be seen: when the objective function is the minimum number of interruptible load users, total interrupt amount of a set of interruptible users selected by ISO

**Table 3** Each node load parameter of IEEE 30 node system

Node Number	Node Amount		Node Number	Node Amount	
	MW	MVAR		MW	MVAR
1	0.0	0.0	16	3.5	1.8
2	21.7	12.7	17	9.0	5.8
3	2.4	1.2	18	3.2	0.9
4	7.6	1.6	19	9.5	3.4
5	94.2	19.0	20	2.2	0.7
6	0.0	0.0	21	17.2	11.2
7	22.8	10.9	22	0.0	0.0
8	30.0	30.0	23	3.2	1.6
9	0.0	0.0	24	8.7	6.7
10	5.8	2.0	25	0.0	0.0
11	0.0	0.0	26	0.0	0.0
12	11.2	7.5	27	0.0	0.0
13	0.0	0.0	28	0.0	0.0
14	6.2	1.6	29	2.4	0.9
15	8.2	2.5	30	10.6	1.9

**Table 4** Maximum interruptible load of users

Node	$\Delta P_{di}^{\max} (MW)$
5	28.26
7	6.84
21	5.25
23	0.96
24	2.61
26	1.05
30	3.18

reaches maximum. When the objective function is the minimum of total interrupt amount, the number of interruptible load users doesn't reach the minimum. The calculation result of the mathematical model of interruptible load can be seen that, the number of interruptible load users reaches minimum, the total interrupt amount close to the minimum. So, the result is optimal.

In traditional multi-objective optimization method, the most widely used is the fuzzy optimization method. This paper will compare the calculated results of the multi-objective optimization scheme calculated by the fuzzy optimization method with being based on constructing evaluation function method. The comparative result is shown in Table 8.

As can be seen from Table 8, the total interrupt amount of interruptible load of the multi-objective optimization method using fuzzy optimization method is 8.902 MW, and the total interrupt amount in constructing evaluation function method is 8.786 MW. The number of interrupt nodes is same 4, but the total interrupt amount has reduced obviously. You can see the interruptible load selection scheme based on constructing evaluation function method being better than fuzzy optimization method.

## 5.2 The relief of the line congestion in the unexpected outage

When the generator unexpectedly shut down, transmission system also will appear congestion. IEEE-30 bus system consists of 6 generators. This paper assumes G6 shut down unexpectedly;

**Table 5** Over slip and overload capacity of three cases

Over Slip	Overload Capacity(MW)		
	Case1	Case 2	Case 3
1-2	123.95	102.50	180.34
1-3	40.78	38.83	0
2-4	18.63	10.18	47.60
3-4	13.03	6.53	0
2-5	0	0	72.24
2-6	49.43	40.98	54.03
4-6	27.18	45.18	7.31
TOTAL	273.00	244.01	289.27

**Table 6** Reduction interruptible load program in normal operation

Node	IL Interrupt Amount(MW)			
	Single Objective			Multi-objective
	$f_1$	$f_2(K_i)$	$f_3(\Delta P_{di})$	
5	1.158	0.159	0.159	1.158
7	0	0.630	0.630	0
21	5.250	4.174	5.250	4.174
23	0	0.960	0.960	0.960
24	2.610	2.610	0	2.610
26	0	0	1.050	0
30	0.575	0	1.449	0

in this case, it is solved separately according to the single objective and multi-objective function to get the cutting interrupt load scheme shown in Table 9. The comparative summary result is shown in Table 10.

Analyzing Table 10 can see that: when the objective function is the minimum number of interruptible load users, total interrupt amount of a set of interruptible users selected by ISO closes to the maximum; when the objective function is according to if the overload matching, the number of interruptible load users reaches the maximum; when the objective function is the minimum number of interruptible load, the number of interrupt users reaches the maximum, the results are not very satisfactory. In the results obtained by linear weighted model, the total interrupt amount is not the lowest, but close to the minimum; the number of interrupt users reaches the minimum, taken together, the selection of interruptible load is still the best results.

The result of comparing the interruptible load selection scheme of fuzzy optimization method with being based on constructing evaluation function method is shown in Table 11.

As can be seen from Table 11, the total interrupt amount of two optimization approaches are 9.207 MW、9.381 MW. The values is so close, but the interrupt number selected by the optimized scheme applying the constructing evaluation function method is 4, the interrupt number of using fuzzy optimization method is 5, so the selected scheme is obviously better than the fuzzy optimization method.

**Table 7** Result of normal operating condition

Objective Function	Single Objective			Multi-objective
	$f_1$	$f_2(K_i)$	$f_3(\Delta P_{di})$	
Overload Capacity	8.435	8.347	9.339	7.744
Total Interrupt Amount	9.593	8.533	9.498	8.786
Interrupt Number	4	5	6	4
Interrupt Branch	2-5	2-4	1-3	2-5

**Table 8** Comparative result of two multi-objective optimization approaches

	Constructing Evaluation Function Method	Fuzzy Optimization Method
Total Interrupt Amount	8.786	8.902
Interrupt Number	4	4

### 5.3 The relief of the line congestion when branch accidentally disconnected

Another case of the line congestion is a branch node in transmission line suddenly disconnected. Solving the single-objective mathematical model and the multi-objective mathematical model twice to get the selected scheme of interruptible load by calculating is shown in Table 12; the summary of calculated result is shown in Table 13.

From Table 13 can be seen: by the former two kinds of analysis procedures, the number of interruptible load users obtained by the mathematical model proposed in this paper closes to the minimum, the total interrupt amount is ideal. Therefore the result obtained by the model is still the best.

The constructing evaluation function method and the fuzzy optimization method are compared to work out the total interrupt amount and interrupt number of interruptible load as shown in Table 14. As can be seen from the table, the total interrupt amount calculated by constructing evaluation function method is 9.208 MW, higher than it in fuzzy optimization method, but the interrupt number less than fuzzy optimization method. To ensure interruptible load selected scheme programs is optimal, price and other factors are also important indicators affecting the ISO selecting interruptible load.

## 6 The application of grid congestion management in oil field

This paper applies the result verifying the IEEE-30 bus system to transmission lines of the grid in an oil field, the node roadmap of torch variable region in this oil power grid is shown in Fig. 2.

**Table 9** Interruptible load cut program in the outage

Node	IL Interrupt Amount(MW)			
	Single Objective			Multi-objective
	$f_1$	$f_2(K_i)$	$f_3(\Delta P_{di})$	
5	0.774	0	0	0
7	0	0.219	0.219	0.219
21	5.250	5.250	5.250	5.250
23	0	0	0.807	0
24	2.610	2.610	0	2.610
26	1.050	1.050	1.050	0
30	0	0.186	2.425	1.302

**Table 10** Result of G6 outage

Objective Function	Single Objective			Multi-objective $F(x)$
	$f_1$	$f_2(K_i)$	$f_3(\Delta P_{di})$	
Overload Capacity	9.250	9.053	9.554	9.171
Total Interrupt Amount	9.684	9.315	9.751	9.207
Interrupt Number	4	5	5	4
Interrupt Branch	3-4	2-5	1-3	3-4

The condition of load of each substation provided by power company is the maximum load of the whole grid between 2007–2008, namely the date at 18:00 on the January 15, 2008, which was enlarged to 300 %, to simulate the condition appearing circuit congestion, partial load data as shown in Table 15.

As shown in Fig. 2, there are 24 branches in torch variable region. Each branch is numbered, and each branch parameter is listed, as shown in Table 16.

The torch variable region of this oil grid is power flow calculated, and the overload branch and overload capacity under three different conditions are calculated separately, as shown in Table 17. Three conditions are as follows: in normal operating condition, transmission lines appear congestion; Feng Yun variable region power outage, transmission lines appear congestion; branch circuit 15 unexpectedly disconnect, transmission lines appear congestion.

This paper calculates and analyzes the torch variable region of this oil grid, simulates transmission congestion in three cases, compares and analyzes the selected scheme of solving three separate single objective function and multi-objective function.

### 6.1 The selected scheme of interruptible load in normal operating condition

As can be seen from the result, the selection condition is single objective. When the minimum number of interruptible load users is objective function (that is, the objective function), the total interrupt amount of interruptible users is 6.587 MW, up to the maximum. When the minimum total interrupt amount is objective function, it is 5.860 MW, and the number of interruptible load users is 3, not up to the minimum. When the multi-objective function as interruptible load selected objective function is solved, as shown in Table 18, the number of interruptible load users of the selected scheme is the minimum. The total interrupt amount does not reach the minimum, but closes to the minimum. So, selected scheme is the best.

**Table 11** Comparative result of two multi-objective optimization approaches

	Constructing Evaluation Function Method	Fuzzy Optimization Method
Total Interrupt Amount	9.207	9.381
Interrupt Number	4	5

**Table 12** Interruptible load cut program of 1–3 branch cuts

Node	IL Interrupt Amount(MW)			
	Single Objective			Multi-objective
	$f_1$	$f_2(K_i)$	$f_3(\Delta P_{di})$	
5	1.906	0.352	0.352	1.906
7	0	0.980	0.980	0
21	4.743	1.910	5.204	5.202
23	0	0.960	0.960	0.960
24	2.610	2.610	0	0
26	0	1.050	1.048	1.050
30	0	0	0	0

### 6.2 Congestion eliminating scheme of unexpected power outage

Table 19 can be analyzed that: if the total interrupt amount of interruptible load is the objective function, the branch overload can be eliminated effectively, but the interrupt number will reach the maximum. In multi-objective optimization conditions, the selected result of interruptible load scheme obtained by the objective function model given in this paper, the number of interrupt users is 2, and total interrupt amount is 6.442 MW, also close to the minimum. And the branch overload can be effectively eliminated. The selected result of interruptible load is the best.

### 6.3 Congestion eliminating of branch 15 disconnection

Analyzing Table 20, you can see that if using the selected condition based on single objective to select interruptible load, the result is not ideal. Especially, when total interrupt amount of interruptible load as the objective function, the interrupt number is 4, reaching the maximum, and overload isn't eliminated effectively. The selected scheme can't taking into account the three objective functions to make it optimal at the same time. In the selected scheme obtained by the model proposed by this paper, the interrupt number is 3, and the total interrupt amount is 6.261 MW. After considering the price factor can be concluded that the selected scheme is still the best.

**Table 13** Result of 1–3 branch-off

Objective Function	Single Objective			Multi-objective
	$f_1$	$f_2(K_i)$	$f_3(\Delta P_{di})$	
Overload Capacity	9.250	7.862	8.544	9.118
Total Interrupt Amount	9.259	7.863	8.545	9.208
Interrupt Number	3	6	5	4
Interrupt Branch	4-6	1-2	2-4,3-4	1-2,2-4

**Table 14** Comparative result of two multi-objective optimization approaches

	Constructing Evaluation Function Method	Fuzzy Optimization Method
Total Interrupt Amount	9.208	9.118
Interrupt Number	4	5

### 7 Conclusion

A lot of ways to solve the problem of network transmission congestion can be used as a reference for power system. For example, the following measures.

Firstly, the network topology is reasonably designed, for some important nodes, the network topology is designed to increase the redundancy.

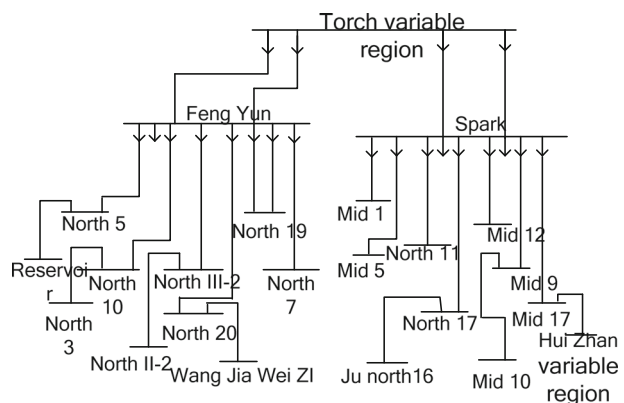
Secondly, the reasonable design of network device buffer size, network congestion is not a long time, is the stage, with the characteristics of the sudden increase in the network equipment can reduce congestion.

Once again increase the load balancing equipment, the traffic load balancing equipment to be carried out to reduce the impact of traffic on the network device, so that the network device to receive the traffic flow is smooth, uniform.

These measures can be used as reference for the power system to solve the transmission congestion. In the Internet of things gradually integrated into the trend of the power system, if the power system wants to ensure the safe and steady operation, it should avoid transmission lines appearing congestion. Transmission congestion will bring a series of problems to the power system, such as adding unnecessary power cost, affecting the price of electricity commodity substantially, increasing the risk the users take, and these problems will threaten the safety of the power system. So, how to effectively manage congestion of transmission lines, constructing mathematical models comply with all the conditions can provide safeguard to improve the reliability of power system operation. The traditional method of transmission congestion management has been unable to effectively eliminate the congestion, interruptible load as a generator backup power resources, is paid more and more attention in the transmission congestion management.

Get the following conclusions:

**Fig. 2** Node roadmap of torch variable region



**Table 15** Torch part of load condition

Statistics of Power Company Substation Load Jurisdiction			
Substation Name	Measuring Position	Active Power (KW)	Reactive Power (KVAR)
Tou Tai Once Substation	110KV Inlet Wire Name		
	Source Line A 01106	48	15
	Source Line B 01107	48	15
	35KVInlet Wire Name		
	Tai Zhao Line A 01137	33	9
	Song Yi Line 01140	3	1.5
	Ao Nan Line A 01139	3	1.5
	Ao Nan Line B 01142	33	0.6
	No. 1 Main Transformer 6(10)KV Switch	24	12
	No. 2 Main Transformer 6(10)KV Switch	0	0

- (1) In the bilateral trade market of power market environment, the OPF algorithm can calculate that the branch circuit in power system out-of-limit and the out-of-limit amount.
- (2) The mathematical model constructed in this paper has a total of three objective functions to optimize: interruptible load match with brand circuit overload, the minimum number of interruptible load users and the minimum number of total interrupt amount. After simulating the IEEE-30 bus system, analyzing its calculation result: no matter which optimization objective alone as the objective function of the model, the final selected scheme of interruptible load is not ideal. But the

**Table 16** Branch capacity parameter of torch variable region

Branch Number	Branch Name	Reference Value(MVA)	Branch Number	Branch Name	Reference Value(MVA)
1	Torch-Feng Yun I	50	13	Torch-Spark I	12
2	Torch-Feng Yun II	34	14	Torch-Spark II	26
3	Feng Yun-North 5	50	15	Spark-Mid 1	26
4	North 5-Reservoir	50	16	Spark-Mid 5	26
5	Feng Yun-North 10	34	17	Sparke-North 11	26
6	North 10-North 3	50	18	Spark-North 17	26
7	Feng Yun-North III2	34	19	North 17-Ju North 16	26
8	North III2-North II2	50	20	Spark-Mid 12	12
9	Feng Yun-North 20	34	21	Spark-Mid 9	12
10	North 20-Wang Jia Wei Zi	56	22	Mid 9-Mid 10	12
11	Feng Yun-North 19	26	23	Spark-Mid 17	12
12	Feng Yun-North 7	56	24	Mid 17-Hui Zhan	12



**Table 17** Overload slip and capacity of three cases

Overload Slip Number	Overload Capacity(MW)		
	Case 1	Case 2	Case 3
1	47.50	37.27	65.77
5	10.67	10.16	0
11	1.72	0.94	4.39
19	13.04	6.54	0
23	0	0	27.79
Summation	72.93	54.91	97.95

mathematical model presented in this paper can take into account the conditions of the three objectives, making three objective functions achieve an optimal state at the same time.

- (3) Analyzing multi-objective model in this paper comprehensively, in the solving method, the evaluation function is introduced. And constructing evaluation function method based on the linear weighted sum is used to optimize the multi-objective problem. This method can transform the multi-objective model into a simple single objective problem by mathematical transformation. Analysis of the simulation calculation results can be seen: constructing evaluation function method can consider the three objective conditions, a more comprehensive analysis than the single objective model.
- (4) In the selected process of determining interruptible load scheme, this paper mainly analyzes three cases: first, in normal operating condition of the power system, second, in the condition of power outage caused an unexpected accident, and the third, in the condition that a transmission line node branch suddenly disconnect. In addition to calculating and analyzing the IEEE-30 bus system, this article applies the multi-objective mathematical model to an actual power grid. The torch variable region of this oil grid is carried on the analysis and calculation also according to the above three conditions. Calculation result shows that: multi-objective mathematical model presented in this paper will be able to respond quickly and make the corresponding processing to eliminate the congestion in such conditions, so as to ensure the safe operation of the transmission line.

**Table 18** Congestion eliminating in normal operating condition

Objective Function	Single Objective			Multi-objective
	$f_1$	$f_2(K_i)$	$f_3(\Delta P_{di})$	
Overload Capacity	5.792	5.794	6.413	5.318
Total Interrupt Amount	6.587	5.860	6.522	6.117
Interrupt Number	2	3	4	2
Interrupt Branch	7	13	18	18

**Table 19** Congestion eliminating of unexpected power outage

Objective Function	Single Objective			Multi-objective $F(x)$
	$f_1$	$f_2(K_i)$	$f_3(\Delta P_{di})$	
Overload Capacity	6.352	6.217	6.561	6.534
Total Interrupt Amount	6.650	6.397	6.696	6.442
Interrupt Number	2	3	3	2
Interrupt Branch	13	2	19	13

The next step research work required:

This paper did a little in the transmission congestion management to explore and discuss, but still can't solve the transmission congestion problem quickly. The implementation of introducing the interruptible load to the transmission congestion management still has problems which are worthy of further exploration.

- (1) In the electricity market, introducing interruptible load to the transmission congestion management to establish the corresponding mathematical model, need that electricity users can report the interruptible load amount and compensation price, etc. to the power company initiatively and truly. But in fact not the case, in order to take full advantage of the interruptible load demand elasticity for electricity goods, power companies should take effective measures to make the electricity users sign the interruptible contract actively.
- (2) The objective function of the mathematical model presented in this paper are respectively that, if interruptible load matching with overload capacity, the least number of interruptible load node at least, the lowest total interrupt amount of interruptible load. In fact, if you want to make full use of the special power resources reserve capacity, only consider these three points are not enough. The optimization of other conditions (such as the interruptible load response time, etc.) can also be used as the objective function of a mathematical model to solve.
- (3) For this paper, multi-objective function is adopted by constructing evaluation function method based on the linear weighted sum method to obtain the optimal selected scheme of interruptible load. The premise of using this method is that the single objective problem transformed must be linear, which can be solved further by the simplex method.

**Table 20** Congestion eliminating of branch 15 disconnection

Objective Function	Single Objective			Multi-objective $F(x)$
	$f_1$	$f_2(K_i)$	$f_3(\Delta P_{di})$	
Overload Capacity	6.352	5.399	5.867	6.261
Total Interrupt Amount	6.358	5.399	5.868	6.261
Interrupt Number	2	4	3	3
Interrupt Branch	8	7	18	18

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