THE OPTIMIZATION OF TIME-OF-USE PRICING CONSIDERING RELIABILITY

Kai CHEN
Nanjing Power Supply Company –China
kaichen78@sohu.com

Dan CHEN
Hohai University –Chin
chendan@hhu.edu.cn

YingChen LIAO
Hohai University –China
orangeliao@hhu.edu.cn

XingYing CHEN
Hohai University –China
xychen@hhu.edu.cn

ABSTRACT

How to introduce reliability into the optimization of TOU is the problem to be solved in this paper. Firstly, we optimizes TOU according to the principle of Pareto efficiency, The objective function is to minimize the difference between peak and valley, while the interests of the power supply company and consumers will not decrease on the premise that network constraints are met. Reliability compensation is introduced into benefit analysis of the power supply company and consumers to take into account the effect of reliability on optimization of TOU. Then we apply the particle swarm optimization algorithm to solve the TOU optimization problem. Finally the simulation analysis of the IEEE 69 nodes system showed, when considering reliability, the peak and valley difference reduced, while the power suppliers' revenue and the economic benefits of the power consumers do not reduce.

INTRODUCTION

In this paper, the TOU price in distribution side makes use of on the basis of reliability in distribution network and tariff electricity elasticity matrix is exploited to consider the response to price. The loads' peak-valley differences of the feeders are as the objective function, which is no harm to the interests of all parties at the same time during the process of the TOU optimization program. The blackouts compensation of the user according to the type of users. The BSO is adopted to get the TOU optimization solution and the test results presented in this paper show that the model and the algorithm have good stability and astringency.

POWER DEMAND ELASTIC MATRIX

Users can follow the load characteristics and distribution price to change their habit. When the electricity price is high, you can reduce the demand for electricity, namely cutting the load, and then cut in electricity prices higher load transfer to periods of low electricity prices, in order to reduce electricity costs and power purchase risk. Price elasticity of demand is defined as the magnitude of changes in demand caused by the change in the ratio of the amplitude of price changes:

$$\varepsilon = \frac{\Delta P / P}{\Delta\lambda / \lambda} \tag{1}$$

Where: ΔP , $\Delta\lambda$, Respectively, for the user side load and electricity price increment; P and λ Were load and electricity price before the user side of the Electric-Rate-change.

In general, the response of the users of electricity mainly in two forms, namely single period response and multi-period response. Single period response refers to the user decides a certain period of time of electricity or less electricity only with the relevant price. The so-called multi-period response, the user is not simply to reduce their electricity consumption, but the load from the high electricity price periods to low electricity price periods, it is not only with the electricity price at the time, but also with other periods electricity price. Therefore, we adopt the concept of self-elasticity coefficient ε_{ii} and cross-elasticity coefficient ε_{ij} , the definition of the corresponding the form as follows:

$$\varepsilon_{ii} = \frac{\Delta P_i / P_i}{\Delta\lambda_i / \lambda_i}, \quad \varepsilon_{ij} = \frac{\Delta P_i / P_i}{\Delta\lambda_j / \lambda_j}\left(i \neq j\right) \tag{2}$$

In this paper TOU power price into three parts price, get the following formula：

$$\begin{bmatrix} P_f \\ P_p \\ P_g \end{bmatrix} = \begin{bmatrix} P_f^0 \\ P_p^0 \\ P_g^0 \end{bmatrix} + \frac{1}{3}\begin{bmatrix} \varepsilon_{11} & \varepsilon_{12} & \varepsilon_{13} \\ \varepsilon_{21} & \varepsilon_{22} & \varepsilon_{23} \\ \varepsilon_{31} & \varepsilon_{32} & \varepsilon_{33} \end{bmatrix} \begin{bmatrix} \lambda_f / \lambda - 1 \\ \lambda_p / \lambda - 1 \\ \lambda_g / \lambda - 2 \end{bmatrix} \begin{bmatrix} P_f^0 \\ P_p^0 \\ P_g^0 \end{bmatrix} \tag{3}$$

Formula: $E = \begin{bmatrix} \varepsilon_{11} & \varepsilon_{12} & \varepsilon_{13} \\ \varepsilon_{21} & \varepsilon_{22} & \varepsilon_{23} \\ \varepsilon_{31} & \varepsilon_{32} & \varepsilon_{33} \end{bmatrix}$ is the power demandtime-sharingpriceelastic matrix; f, p, g are the peak, flat and valley periods. $\lambda_f, \lambda_p, \lambda_g$ are the peak, flat and valley power price after tou power price; λ is the single price before tou power price; P_f, P_p, P_g are the peak, flat and valley loads after tou power price; P_f^0, P_p^0, P_g^0 are the peak, flat and valley loads before TOU power price.

COMPENSATION AND EVALUATION OF RELIABILITY OF POWER SUPPLY

Failure model

Historical data show that the failure rate of the power distribution unit varies with the geographic distribution 、 weather and load level. In some regions, operating experience shows that there is a high correlation between failure rate and feeder load carried. Therefore, if lose electric data incomplete, failure rate weighting factor can be determined based on the relationship between the failure rate and the feeder load. Feeder segment failure rate under a load level by the average failure rate multiplying the time-varying weight factor：

$$\mathrm{r}_j(t) = \mathrm{r}_{j,avg} \times W_j(t) \quad (4)$$

Where: j represents the user type， $\mathrm{r}_{j,avg}$ is j class average failure rate, $\mathrm{r}_j(t)$ is j class of users t moment of failure rate, $W_i(t)$ is j class of users weighting factor of time failure rate.

User blackout cost model

Industrial, commercial and residential user's average power cost has been studied by many countries. For a particular system, the average user power cost of a given load level and power failure time will change over time. Time-varying cost weighting factor can get through the user power cost statistics. Each feeder structure corresponds to a reliability change curve. Considering each load point failure rate, the expected time of the outage the user damage function can calculate the given load point, feeder and system power cost. The user total blackout costing model as follows:

$$TCIC = \sum_{t=1}^{24}\sum_{j=1}^{n} \mathrm{r}_j(t) \bullet rat_j(P,t) \bullet P(t) \quad (5)$$

Where: j represents the user types, n for the user total number of types, $\mathrm{r}_j(t)$ is j Class of users t moment of failure rate, $rat_j(t)$ for the first j Class of users in t moment of the proportion of the share of the load feeders, $L(t)$ for feeder t the total load of the moment.

User value and reliability compensation

Value have different meanings in different areas. Value engineering is used to evaluate things beneficial. Expressed as the ratio of resources devoted to the utility of things and get this utility. The user value is defined as: The ratio of user perception of the profits and the perceived cost. User perception of profits according to their own needs and preferences, quantification of its various benefits obtained from the entire product; the user perceived cost users purchase and use of goods incurred costs quantified. If represents the user value, represents the user perception Profits, represents the cost of user perception, the user value is defined as:

$$V_C = \frac{F_C}{C_C} \quad (6)$$

Price-driven user value approaching function is a dynamic adjustment model of commodity prices, which based on user value theory and make the user value of goods (V_P) to closer to the ideal user value(V_C),that is, $V_P \to V_C$, in order to better to meet the needs of users, and to continue to improve the competitiveness of commodities. The ideal user value is the best goods from the user's point of view, which is the best of its user value. Meanwhile, due to the changing needs of users, user value V_C has a dynamic, so V_C continuous adjustments and amendments according to changing user needs.

TOU sectorization of the peak-to-valley usually segment the user value approach function is defined as follows:

$$\begin{aligned} V_{Pfi} &= \frac{F_{Pfi}}{C_{Pfi}} = \frac{T_f L_{fi} P_{0fi} + P_{Cfi}}{T_f L_{fi} P_{fi} + \Delta CL_{fi}} \\ V_{Ppi} &= \frac{F_{Ppi}}{C_{Ppi}} = \frac{T_p L_{pi} P_{0pi} + P_{Cpi}}{T_p L_{pi} P_{pi} + \Delta CL_{pi}} \\ V_{Pgi} &= \frac{F_{Pgi}}{C_{Pgi}} = \frac{T_g L_{gi} P_{0gi} + P_{Cgi}}{T_g L_{gi} P_{gi} + \Delta CL_{gi}} \end{aligned} \quad (7)$$

The choice of user is primarily based user value to measure. Therefore, commodity to survive the fierce competition and development, it must as much as possible so that users value close to 1. The user value approaching function derivation, users get the reliability of the compensation is defined as follows:

$$\begin{aligned} P_{Ci} &= \sum_{j=f,p,g} T_j L_{ji}(P_{ji} - P_{0ji}) + \Delta CL_{ji} \\ \Delta CL_{ji} &= TCIC'_{ji} - TCIC_{ij} \end{aligned} \quad (8)$$

TIME-OF-USE PRICE CONSIDERING RELIABILITY MODEL

Objective function

In this paper the main purpose of the implementation of the TOU electricity price is peak clipping in valley, it is to point to minimization the load curve maximum peak, and improve the rate of whole system; So as to improve the economy and stability of whole power system operation, the objective function is:

$$\min\left[\max_{1\le t\le 24}\sum_{i=1}^{n} P_{Di,t}\left(\lambda_f, \lambda_p, \lambda_g, t\right)\right] \quad (9)$$

Where, j is the type of load .1 stands for Industrial load; 2 stands for Commercial load; i is the number of users （ $i = 1,\cdots,n$ ）； t is the time number （ $t = 1,\cdots,24$ ）； $P_{Di,t}$ is the power consumption of The i user t time number after implementation of the TOU

Constraint condition

In this paper, The reasonable optimization of TOU has been point. Reasonable TOU must meet an important demand-side management guidelines, that benefit society, the power company, the user tripartite or several parties benefit and the other party will not be harmed. In simple terms, It refers to the power company's interests are not reduced, as well as the unit of user's purchase cost does not increase. Here we use the Pareto improvement to research this problem: without reducing the welfare of the one of the party, by changing the existing allocation of resources and improve the welfare of the other.

(1)Power supply company will not reduce the income

Time-of-use electricity price before optimization of power supply company power purchase cost

$$T_e^0 = \lambda_{wf}\sum_{t\in T_f}\sum_{i=1}^{n} P_{Gi,j,t}^0 + \lambda_{wp}\sum_{t\in T_p}\sum_{i=1}^{n} P_{Gi,j,t}^0 + \lambda_{wg}\sum_{t\in T_g}\sum_{i=1}^{n} P_{Gi,j,t}^0$$

Charge income is

$$T_i^0 = \sum_{t\in T_f}\sum_{i=1}^{n}\lambda_{j,f}^0 P_{Di,j,t}^0 + \sum_{t\in T_p}\sum_{i=1}^{n}\lambda_{j,p}^0 P_{Di,j,t}^0 + \sum_{t\in T_g}\sum_{i=1}^{n}\lambda_{j,g}^0 P_{Di,j,t}^0$$

The pay compensation for reliability of the power supply company:

$$C^0 = \sum_{t=1}^{24}\sum_{j=1}^{n}\omega_j \bullet r_j(t) \bullet rat_j(P,t) \bullet P^0(t)$$

The profits of power supply company is :

$$T^0 = T_i^0 - T_e^0 - C^0 - \gamma^0$$

Power purchase cost after TOU optimized of the power supply company is:

$$T_e = \lambda_{wf}\sum_{t\in T_f}\sum_{i=1}^{n} P_{Gi,j,t} + \lambda_{wp}\sum_{t\in T_p}\sum_{i=1}^{n} P_{Gi,j,t} + \lambda_{wg}\sum_{t\in T_g}\sum_{i=1}^{n} P_{Gi,j,t}$$

Charge income is

$$T_i = \sum_{t\in T_f}\sum_{i=1}^{n}\lambda_{j,f} P_{Di,j,t} + \sum_{t\in T_p}\sum_{i=1}^{n}\lambda_{j,p} P_{Di,j,t} + \sum_{t\in T_g}\sum_{i=1}^{n}\lambda_{j,g} P_{Di,j,t}$$

Reliability compensation

$$C = \sum_{t=1}^{24}\sum_{j=1}^{n}\omega_j \bullet r_j(t) \bullet rat_j(P,t) \bullet P(t)$$

The profits of power supply company:

$$T = T_i - T_e - C - \gamma$$

In order to ensure the enthusiasm of the power company while optimize TOU. Should be to ensure that the interests the of power company did not reduce after optimization of TOU. So:

$$T \ge T^0 \qquad (10)$$

(2) The user purchase of electricity costs do not increase

Before optimizing TOU, user unit power purchase costs is λ

$$\lambda^0 = \frac{\sum_{t\in T_f}\sum_{i=1}^{n}\lambda_{j,f}^0 P_{Di,j,t}^0 + \sum_{t\in T_p}\sum_{i=1}^{n}\lambda_{j,p}^0 P_{Di,j,t}^0 + \sum_{t\in T_g}\sum_{i=1}^{n}\lambda_{j,g}^0 P_{Di,j,t}^0}{\sum_{t=1}^{24}\sum_{i=1}^{n} P_{Di,j,t}^0}$$

After optimizing TOU, in normal section, peak section and valley section the electricity consumption is:

$$\sum_{t\in T_f}\sum_{i=1}^{n} P_{Di,j,t},\ \sum_{t\in T_p}\sum_{i=1}^{n} P_{Di,j,t},\ \sum_{t\in T_g}\sum_{i=1}^{n} P_{Di,j,t}$$

After optimizing TOU, the price is $\lambda_f, \lambda_p, \lambda_g$, Unit power purchase cost is

$$\lambda = \frac{\sum_{t\in T_f}\sum_{i=1}^{n}\lambda_{j,f} P_{Di,j,t} + \sum_{t\in T_p}\sum_{i=1}^{n}\lambda_{j,p} P_{Di,j,t} + \sum_{t\in T_g}\sum_{i=1}^{n}\lambda_{j,g} P_{Di,j,t}}{\sum_{t=1}^{24}\sum_{i=1}^{n} P_{Di,j,t}}$$

In order to ensure the positive response by the user, it should be guaranteed that no increase in the average unit cost after optimizing TOU for users, that is:

$$\lambda \le \lambda^0 \qquad (11)$$

(3)Price adjustment constraints

This article set the amplitude of each tariff adjustment should not be too large. Set to plus or minus 50% on the basis of the original tariff

$$\frac{\left|\lambda_{j,f} - \lambda_{j,f}^0\right|}{\lambda_{j,f}^0} \le 50\% \qquad (12)$$

NUMERICAL RESULTS

The IEEE69 nodes distribution system is used in this article for simulation and calculation, The IEEE69 node system is mainly constituted by the commercial, industrial and residential load , the specific capacity constitute is shown in Table 1:

Table1 Load constitute

Type of load	Commercial loads （kW）	industrial loads （kW）	residential loads （kW）
IEEE69	482	2189.44	1130.75

According to the fitting of large scale of load data in Hexi area of Nanjing, we get the typical load curve, as shown in the table 1, due to the different electrical characteristics o all kind s of loads, the performance typical load curve is also different, the most obvious manifestation is the peak of evening of the residents load.

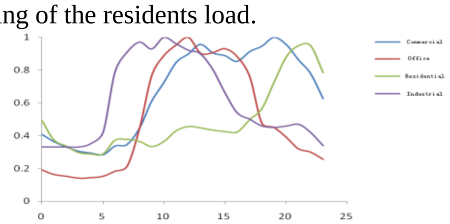

Fig. 1 Typical load curve

The peak hours used in this article is (8:00-12:00, 17:00-21:00), peace time (12:00-17:00, 21:00-0:00), Valley Time (0:00-8: 00), 8 hours for each period. The initial electricity price used in this article is shown in the following table:

Table 2 Initial electricity price

Type of Price	Peak	Peace	Valley
Commercial（Yuan/ kWh）kWh）	1.2103	0.7625	0.3413

Residential（Yuan/ kWh）	0.5583	0.5283	0.3583
Industrial（Yuan/ kWh）	1.1016	0.6895	0.3010
purchasing（Yuan/ kWh）	0.5359	0.4550	0.3485

The tariff ranges from -50% to 50%, that is mean the maximum tariff change plus or minus 50%. Set the population size of the particle swarm algorithm 50, the number of iterations to 50 times, we get the optimal particle of calculation IEEE69 node system is [-0.50 -0.50 0.50 -0.316 -0.50 0.50 -0.50 -0.328 0.500]. It means that the price of electricity of resident load in peak period is increased by 50%, in segment period is increased by 50%, in valley period is reduced by 50%. But, the price of electricity of commercial load in peak period is increased by 31.6%, in segment period is increased by 50%, in valley period is reduced by 50%,; the price of electricity of industrial load in peak period is increased by 50%, in segment period is increased by 32.8%, in valley period is reduced by 50%.

According to the elasticity of demand for various types of load and tariff adjustments, the result of the optimization of the power obtained is as follows:

Table 3 The electricity consumption after optimization

electricity consumption(kWh)		Commercial	industrial	residential
Peak	Before	2292.12	11192.42	1857.05
	After	2177.47	10011.57	1824.09
Peace	Before	2696.28	11172.71	2043.29
	After	2593.14	9946.80	2007.02
Valley	Before	1140.36	6344.99	1463.92
	After	1275.43	7559.66	1639.83

The Figure 2 shows the feeder load curve comparison chart of IEEE69 node system before and after the price adjustment.

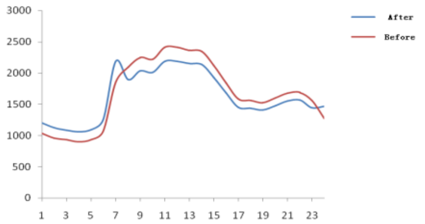

Fig.2 The IEEE69 load curve of the price adjustment before and after

Table 4 profit of each part

	power company's increase(Yuan)	user's average price (Yuan)	Reliability compensation(Yuan)	reliability rate
Before	11107.37	0.7384	116.74	99.9657%
After	11107.78	0.7111	100.37	99.9681%

On the view of the income of each part, the optimization process taking into account the interests of all parties, the power company's increase, so that they have the enthusiasm to have the implementation of TOU; user's average price of electric is also reduced, allowing the user to actively participate in response to the TOU price policy. On the point of reliability, optimized power supply reliability rate is improved to some extent. while the optimization process taking into account the interests of all parties, the power supply reliability rate of the distribution network is also improved ,the reliability of user compensation can also be reduced accordingly, and thus an overall reduction in the running costs of the grid.

CONCLUSION

This paper basis on the TOU optimized, proposed reliability compensation method, summarized the TOU optimization model, and use of the proposed particle swarm algorithm for its solving.

TOU price optimization, in order to the feeder load the lowest peak and valley difference for goals, taking into account the interests of all parties, and that the power company's income does not reduce the user's power purchase cost does not increase. In reliability, user blackout compensation, in line with the laws of the market, to establish the TOU meter and reliability optimization model, the last combination of various types of load electricity tariff elastic, used particle swarm algorithm for solving the optimal solution. Numerical results show that the proposed model and algorithm can well solve TOU meter and reliability optimization problems, the same time, the algorithm is not only able to quickly converge to the global optimum, but also has good stability.

Acknowledgments

This work was supported by the National High Technology Research and Development of China 863 Program (2012AA050214) and Jiangsu Province 2012 annual College graduate research and innovation programs(CXLX12_0233)

REFERENCES

[1]Yijia, Cao. Shengwei, Tang Canbing, Li. An Optimized EV Charging Model Considering TOU Price and SOC Curve. Smart Grid, IEEE Transactions on, 2012. 3(1): 388-393.

[2]Hu Funian, Tang Yudong, Zou Yun. Analysis of Impacts of TOU Price Strategy. Transactions of china electrotechnical society. 2007, 22(4):168-174.

[3]TAN Jinjing, WANG Beibei, LI Yang. Modeling of User Response to Time-of-Use Price Based on Multi-Agent Technology. Power System Technology, 2012, 36(2): 257-263.

[4]Hatami, A., H. Seifi and M.K. Sheikh-El-Eslami. A Stochastic-Based Decision-Making Framework for an Electricity Retailer: Time-of-Use Pricing and Electricity Portfolio Optimization [J]. Power Systems, IEEE Transactions on, 2011,26(4):1808-1816.