Strategic Study on Reduction of Loading Rate of the Distributing Line based on Demand Response

B. R. PAN, Y. ZHANG, Y. WAN, G. N. WANG, X. Z. GUI, Y. YANG
Jiangxi Electric Power Research Institute, Nanchang, China

ABSTRACT: It is an important measure to reduce the loading rate of the distributing line and boost the reliability of the power supply by the power system. At present, the methods to reduce the loading rate of the distributing line generally include power cuts, capacity increase and load transfer. The text proposes to adopt the method to reduce the loading rate of the distributing line by virtue of a kind of lateral parameters. Adopting the demand response strategies which is based on incentives and which takes the maximum economic efficiency as the objective function for controllable load relief, it discusses the influence of different load control schemes on reduction degree of the load. Finally, the study verifies the feasibility of the proposed method in light of the instance data. Results reveal that the demand response means based on incentives could lower the loading rate of the distributing line in a maximum manner, guaranteeing the safe and stable running of the power system.
KEYWORD: Demand Response; Loading Rate of the Distribution Line; Economic Efficiency; Controllable Load.

1 FOREWORD

With the increasing influence of the power system on the national economy, it is of important significance to improve the reliability of the power supply of the power system. Providing the electrical load directly for users, the power distribution network is the ultimate and the most important link in the power supply. Nowadays, not a few power failure is caused by the high loading rate of the power distribution network. The weak wire frame of the distribution network and weak abilities of power supply of the distributing line form a number of power supply bottlenecks, which have difficulties in replying the seasonal, period and regional sudden load increase, most likely to form overload for the distributing line. As a result, it is especially important to how to reduce the loading rate of the line and improve the reliability of the power system [1-3].

To solve the high loading rate of the transmission loan, the grid company generally adopt the following measures in maintenance management: 1) capacity increase reconstructuring: in addition to traditional capacity increase methods for the distributing line such as increasing transmission pressure, adopting the wire with large section, and adopting heat-resisting wire, we may consider to adopt capacity increase optimization for the distributing line, for example, the uniform math model for the capacity increase of the power distribution network is created, the voltage quality or economic benefits and restrictions are compiled, and the optimum capacity increase is realized by virtue of electric assistant software finally after the optimum wire frame of the distributing line for capacity increase is determined, and each capacity increase branch is determined by virtue of the minimum spanning tree and the power supply radium is calculated in light of the mathematical algorithm. 2) Loan transfer: the compensation is conducted by adopting the same three-phase capacity and inductance and active power filter in parallel, the single-phase load is transferred by designing the load shifter in coordination with swift opening and cutting off features of power electronic devices, the optimum allocation is realized by transferring the load through the switch array once it is overload by measuring the three-phase bus voltage and current and transferable loan impedance, calculating the optimum loan distribution mode based on the corresponding optimum algorithm, and setting the loan on one boundary [4-5]. Because the traditional urban distribution network of China adopt the radiation power supply mode more, and the load often cannot be transferred in case of overload of the distributing line, the methods of power failure and limited power are only available to remit the overload in most circumstances accordingly. 3) Power cuts: power cuts are adopted under the conditions that the above schemes fail to reduce the loading rate of the distributing line effectively, the economic efficiency is guaranteed after the district and time for power cuts based on the local power supply mode, loan nature and building scale. However, in many cases, factors relating to the users cannot be given full consideration, so it is inevitable to bring numerous losses [6].

To safeguard the interests of the users, to avoid the power cuts, and minimize the adverse influence that the power supply and demand contradiction results in, it is of profound and realistic significance to explore the strategies with active participation of the users which could safeguard the safe and stable power system. Currently, with the great impetus given to the construction of smart grid and gradual reform on the power market, the pluralism of the interest subject in the power system becomes more and more obvious, as one of the important participants in the competitive and open markets, the role of the demand of the users on aspects of emphasizing economic running and ensuring safety and reliability of the system becomes more and more remarkable. The traditional prevention and control measures don’t take the subject will into account, group control is conducted generally based on the controllable capacity of customers of the power, which comes in intensive administrative colors and relies on the support of governmental policy documents, and under normal conditions, the response time for the users is the fixed alarm time, often resulting in much losses for the users [7]. One of the implementation objectives of the power demand response is to guide the power users to properly reduce the power utilization in the peak period and increase the power utilization at a low ebb so as to reach the purpose of cutting the peak and adding the low ebb and improve the load curve. The demand response is applied to the reduction of loading rate of the distributing line. Proper improvement in response will, users classification and electricity price execution and other aspects makes the mitigation measures for overload transformed from stiffness control to flexible control. Meanwhile, the demand response may be used in combination with traditional methods such as load transfer, which is aimed at realizing the safe and stable power system and optimum economic benefits.

Demand side response based on the price incentives fails to realize due to the constraint of the current domestic electricity price mechanism, mainly taking the demand response mechanism based on the incentives as the entry point, the text regards users as a kind of power resource with reduction of overload of distributing line as the objective, researches the function mechanism of demand response, and gives the lateral parameters of users and relevant strategies and realization model on reduction of the loading rate of the distributing line in simulated analysis.

2 CREATION AND ANALYSIS OF MODEL OF REDUCTION OF LOADING RATE OF THE DISTRIBUTING LINE

2.1 *Analysis on Severe Results of Overload of the Distributing Line* [8]

The influence of overload of the distributing line on the system is considered from two aspects including economic losses of the power supply and users, the severe results of overload of the distributing line mainly take into account the sale cost of electricity, standby cost for controllable load, maintenance and starting cost of elements and load losses of users, and others.

The standby cost of controllable loan include capacity cost and electric quantity cost. Capacity cost has nothing to do with accidents, a fixed cost that users of lateral parameters and controllable loan shall pay under the contract; the study adopts the electricity price discount mode and the cost will not be reduced even if the load is not suspended within the scope as specified in the contract; electricity quantity cost is the risk cost relating to the accident probability, occurring after the accident happens and controllable load is invoked.

The interruptable capacity cost of the ith user to purchase is:

$$C_{ILLi} = C'_{ILLi} Q_{ILLi} \tag{1}$$

In the formula, C'_{ILLi} is the electricity price discount for the ith user as provided in the contract, and Q_{ILLi} is the reduction quantity of the load of the ith user as provided in the contract.

The interruptable electricity quantity cost of the ith user to purchase is:

$$C_{ILi}^{j} = \sum_{i} C_{3i} P_{IL,i}^{j} \Delta t I_i^j \tag{2}$$

In the formula, C_{3i} is the unit reduced loan cost of the ith user as provided in the contract, $P_{IL,i}^{t}$ is the reduction quantity of the load at the jth period of the ith user; Δt is the suspension time for each period; I_i^j is the invoking status of the controllable load, $I_i^j = 1$ means the controllable load is invoked; $I_i^j = 0$ means the controllable load is not revoked [9].

a) Economic Losses for Overload of Power Supply

After overload of the distributing line, when load shedding is inevitable, the transmission party shall provide certain compensation for users in accordance with requirements of the contract and agreement. Hence, the transmission company not only suffers from benefit reduction due to drop of transmission capacity but also bears the capacity and electricity quantity cost required for controllable load. The total economic losses L_T are:

$$L_T = \sum_i \sum_j (C_{2i} - C_1) \times P_{IL,i}^j \Delta t I_i^j + \sum_i \sum_j C_{ILi}^j + \sum_i C_{ILLi} \quad (3)$$

In the formula, C_{2i} is the sale price of the electricity of the grid company for the users of the category i; C_1 is the grid purchase price of the power station; $P_{IL,i}^j$ is the suspended load quantity of the ith user at the jth period; C_{ILLi} is the interruptable capacity cost of the ith user to purchase; C_{ILi}^j is the interruptable electricity quantity cost of the ith user to purchase [10].

b) Economic Losses for Overload of Users

Under the conditions of power market, the controllable load contracts signed by different users as per their own requirements on quality of electric power and reliability of power supply and the grid company are diversified. The outage cost that the users suffer is under the influence of dependence degree of users on the electricity and outage mode and time and other relevant factors: for example the categories of users, outage notice in advance, outage time, duration of outage and power supply agreement, etc.. The total economic losses caused by suspended load L_U are:

$$L_U = \sum_i \sum_j (r_i \times P_{IL,i}^j \Delta t I_i^j - C_{ILi}^j) - \sum_i C_{ILLi} \quad (4)$$

In the formula, r_i is the unit outage loss for various users.

2.2 *The Controllable Load IL Joins Creation of Model of Reduction of Loading Rate of the Distributing Line* [11]

2.2.1Objective Function

In case of overload in distributing line, necessary load added for keep safe running of the system results in suspension of power supply.

Because the controllable load has considered the economic value and importance degree, the consequences of overload of the distributing line shall take the minimum total economic losses of each subject of the market caused by the loading relief, and it is shown as follows:

$$Min \quad Sev = L_T + L_U \quad (1)$$

2.3.2Constraint Conditions

a) Minimum Relief Capacity and Maximum Interruptable Capacity Constraint

The loading suspension amount of the ith user at certain period shall be larger than minimum relief capacity as provided in the controllable load contract of of the ith user, and shall be less than the minimum interruptable capacity of such as user, namely:

$$P_{IL,i}^{\min} \le P_{IL,i} \le P_{IL,i}^{\max} \quad (2)$$

In the formula, $P_{ld,i}^{\min}$ and $P_{ld,i}^{\max}$ are respectively the minimum relief capacity and maximum interruptable capacity.

b) Constraint of the Total Loading Capacity Actually Joining the Suspension

When overload occurs, the total loading capacity joining the suspension actually shall be larger than or be equal to the loading capacity relieved out of overload so as to guarantee the the normal power utilization of power users is free from overload influence in an uttermost way, namely:

$$\sum_i P_{IL,i} \ge \Delta P \quad (3)$$

In the formula, ΔP is the loading capacity relieved out of overload.

2.3.3 Constraint on Benefits of Users

To facilitate active participation of users in management on controllable load, it is necessary to let users participating in ILM gain certain benefits, that is, the economic losses are less than or equal to zero, and the constraint conditions are as follows:

$$L_u \le 0 \quad (4)$$

3 EXAMPLE OPTIMIZATION AND RESULT ANALYSIT

3.1*Basic Data*

The example analysis is conducted based on the loading data of the industry, business and resident users in certain region with consideration into the unit feeder taken, among which, the loading is composed of the loading of the following industry, business and resident users.

3.1.1Industry Loading

a)The metal smelting industry consumes a large sum of electricity quantity with average daily loading rate between 70% to 80%, and it demands highly reliable power supply, the incentive modes for controllable load are normally available due to a lot of equipment for continuous production, relatively centralized loading, and high coincidence factor and high loading rate as well.

b) With the triple shift system for continuous production, the apparel manufacturing’s electricity utilization is balanced and stable with daily electricity loading rate up to over 92% and average daily load being 1250kW, while the given controllable load contract scheme is 180kw, leaving the compensation price being RMB 2.4/kw.

c) With double shift production, a certain metal processing enterprise's load is not much, so they choose to produce at daytime and evening, and they stop work before dawn, leaving the small daily loading rate of 50%, and average daily load being 215kw.

d) With the triple shift system for continuous production, a certain electronics manufacturer, a certain electronic manufacturer has three loading peaks, respectively at 2:00, 9:00, and 16:00, and average daily load is 702kw, and the loading rate is 75% as well; the given interruptable contract scheme is 120kw, and compensation price is RMB 2.8/kw.

e) With the large proportion of the electric charge in production cost, a certain building material manufacturer chooses to produce at night with average daily load of 615kw, and daily loading rate being lower, and high sensitivity to electricity price as well.

f) With the triple shift system for continuous production, a certain ceramic manufacturing enterprise's electricity utilization load is balanced and stable with daily loading rate of 90%, given controllable load scheme of 100kw and compensation price of RMB 2.5/kw.

The daily loading curve of industry loading is shown as Figure 1:

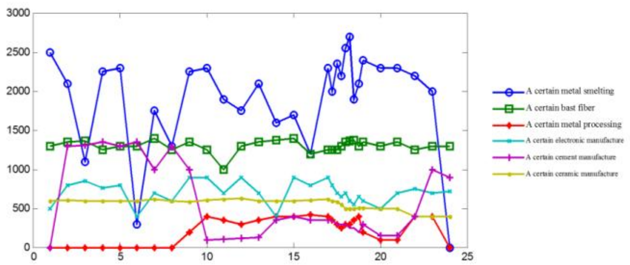

Figure1. Daily Loading Curve of Industry Loading.

3.1.2*Business Loading*

The general traits of the business loading lie in the strong seasonality and timeliness, and business loading has become the major part of the peak loading for the grid, meanwhile, the operational mode and constitution of the business system are relatively uniform, and the loading curves don't vary much.

a) The supermarket and the furniture store has increasing loading during the period from about 7:00 am to 9:00 am, and a sudden fall at about 9:00 pm to 10:00 pm. The interruptible contract scheme for the supermarket and the furniture store is 120kw, and the compensation price is RMB 2/kw. And such types of loading are not sensitive to price response.

b) A certain industry, the rise in the curve happens at about 7:00 to 9:00 and drop happens at about 9:00 to 10:00. It is sensitive to the price, and the given interruptable contract scheme is 450kw, and the compensation price is RMB 3/kw.

c) A certain hotel, the daily loading curve is stable with small fluctuation, and there is evening peak due to start of nightlighting at night.

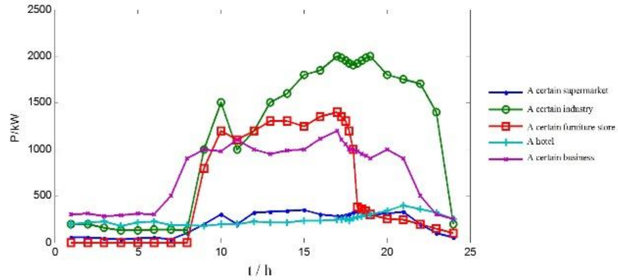

Figure2.Daily Loading Curve of Business Loading.

3.1.3*Appliance Load*

The appliance load changes greatly with great time changes within one day and daily change within a year and strong randomness, and the loading quantity varies within 24 hours in a day with light load at night and heavy load at daytime, and the seasonal loading is relatively outstanding as well with obvious loading in the winter and the summer.

30 appliance loads are selected, among which there are five users with heavy electricity utilization, and the peak of 350kw, and there are 25 small users with the peak of 120km, and the power size in each period occurs in random and the prime time at night, namely 17:00 to 19:00 is the peak for electricity utilization.

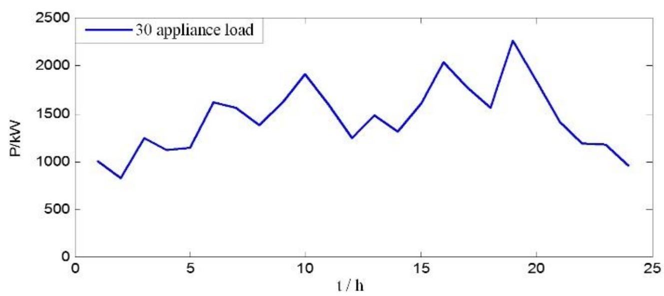

Figure3. Total Daily Loading Curve of 30 Resident Users in the Objective Area.0

3.2 Simulated and Result Analysis

3.2.1 *Setting for Conditions and Parameters*

In the study, it is assumed that users have chosen proper interruptable contract and the contract example is as follows:

Contract: suspension lasts for 2 hours, and suspension time is 17:00 to 19:00, suspension relieved loading PkW, and the unit suspension compensation allowed by the fund plan of the grid company is RMB n/kWh.

3.2.2 *Analysis of Optimization Results*

Load shedding operation is conducted for part exceeding 11500kW in the study.

The load shedding is indicated in a 16×9 array, 16 lines respectively show 16 controllable loans selected (for the convenience of sorting calculation, controllable load not adopted is also calculated using the data 0/0) and every 15 minutes works as a period, and 19:00 to 21:00 is divided into 9 periods accordingly as well, and 9 rows show the 9 periods. Adjust the array to the form of table 3, among which, the interruptable contract is indicated in P/n in example simply, and the load with a tick means the controllable load required to be executed, among which, the resident load only selects 5 users with heavy electricity utilization to participate in the controllable load incentives.

Table 1 .Statistics on Load Shedding of Controllable Loan.

		Interruptable Contract (P/n)	1	2	3	4	5	6	7	8	9
Industry	Metal Smelting	0/0									
	Apparel Manufacturing	200/2.5	√		√						
	Metal Processing	0/0									
	Electronic Manufacturing	100/3									
	Building Material Manufacturing	0/0									
	Ceramic Manufacturing	100/2.5	√		√	√	√				
Business	Supermarket	100/2	√	√	√	√	√				
	Industry	400/3	√								
	Furniture Store	100/2	√	√	√	√	√				
	Hotel	0/0									
	Business	200/2.5	√		√	√					
Partial Appliance	1	50/2	√	√			√				
	2	50/2	√	√		√					
	3	50/2	√		√		√				
	4	50/2	√	√	√	√	√				
	5	50/2	√	√	√	√	√				

Reflect table 1 into the loading curve, as is shown in Figure 4.It is known from Figure 4 that the part of the daily loading curve exceeding 11500kW from 16:00 to 18:00 is relieved in the mode of minimum losses of economic benefits after application of controllable load incentives, and the maximum load drops from 12715kW to 11449kW after optimization adjustment, accounting for about 9.94% of original maximum load, showing that demand side response based on the incentives has good peak clipping effect, and the loading rate of the distributing line may be lowered effectively.

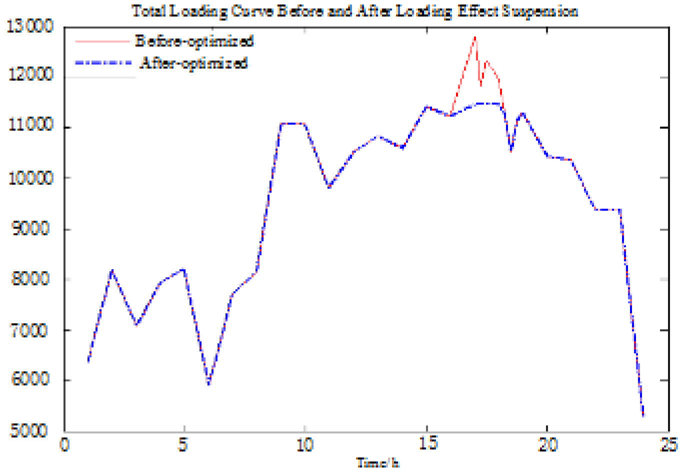

Figure4. Effect Picture after Optimization.

4 CONCLUSION

The text chooses the controllable load as the example in the demand response incentive mechanism to represent the action mechanism. The objective of maximum economic efficiency and control on certain controllable loads at peak periods bring good peak clipping effect. So application of reasonable controllable loan contract model makes for reducing electricity utilization loading at peak periods, avoiding or reducing the losses that the users suffer for rigid power cuts, improving the liability and economic efficiency of the running of the system.

REFERENCES

[1] Srinivasan, D., Liew, A. C., & Chang, C. S. 1994. Forecasting daily load curves using a hybrid fuzzy-neural approach. *IEE Proceedings-Generation, Transmission and Distribution*, 141(6), 561-567.

[2] Xie, X. L., & Beni, G. 1991. A validity measure for fuzzy clustering. *IEEE Transactions on pattern analysis and machine intelligence*, 13 (8), 841-847.

[3] Handschin, E., & Dornemann, C. 1988. Bus load modelling and forecasting. *Power Systems, IEEE Transactions on*, 3 (2), 627-633.

[4] Chow, T. W. S., & Leung, C. T. 1996. Neural network based short-term load forecasting using weather compensation. *Power Systems, IEEE Transactions on*, 11 (4), 1736-1742.

[5] Heinemann, G. T., Nordmian, D. A., & Plant, E. 1966. The relationship between summer weather and summer loads-A regression analysis. *Power Apparatus and Systems, IEEE Transactions on*, (11), 1144-1154.

[6] Gupta, P. C., & Yamada, K. 1972. Adaptive short-term forecasting of hourly loads using weather information. *Power Apparatus and Systems, IEEE Transactions on*, (5), 2085-2094.

[7] Lijesen, D. P., & Rosing, J. 1971. Adaptive forecasting of hourly loads based on load measurements and weather information. *Power Apparatus and Systems, IEEE Transactions on*, (4), 1757-1767.

[8] Hyde, O., & Hodnett, P. F. 1997. An adaptable automated procedure for short-term electricity load forecasting. *Power Systems, IEEE Transactions on*, 12 (1), 84-94.

[9] Kirschen, D. S. 2003. Demand-side view of electricity markets. *Power Systems, IEEE Transactions on*, 18 (2), 520-527.

[10] Zhou, M., Li, G., Zheng, Y., Yang, J., & Qi, J. 2007, July. An integrated approach on allocating the fixed wheeling cost of large consumers considering time-of-use pricing and power quality. *In Power Tech*, 2007 IEEE Lausanne (pp. 920-925). IEEE.

[11] Gavrilas, M., Sfintes, V. C., & Filimon, M. N. 2001. Identifying typical load profiles using neural-fuzzy models. *In Transmission and Distribution Conference and Exposition, 2001 IEEE/PES* (Vol. 1, pp. 421-426). IEEE.