

Li, Na; Wang, Xiaoliang; Zhu, Zhenhua; Wang, Yanan

Article

The reliability evaluation research of distribution system considering demand response

Energy Reports

Provided in Cooperation with:

Elsevier

Suggested Citation: Li, Na; Wang, Xiaoliang; Zhu, Zhenhua; Wang, Yanan (2020) : The reliability evaluation research of distribution system considering demand response, Energy Reports, ISSN 2352-4847, Elsevier, Amsterdam, Vol. 6, Iss. 2, pp. 153-158, <https://doi.org/10.1016/j.egy.2019.11.056>

This Version is available at:

<https://hdl.handle.net/10419/243872>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<https://creativecommons.org/licenses/by-nc-nd/4.0/>

The 6th International Conference on Power and Energy Systems Engineering (CPESE 2019),
20–23 September 2019, Okinawa, Japan

The reliability evaluation research of distribution system considering demand response

Na Li^{a,*}, Xiaoliang Wang^b, Zhenhua Zhu^a, Yanan Wang^a

^a State Grid Shandong Electric Power Research Institute, Jinan, 250002, China

^b State Grid Shandong Electric Power Maintenance, Jinan, 250000, China

Received 2 October 2019; accepted 22 November 2019

Abstract

In order to evaluate the reliability of distribution system with demand response, this paper established the load peak–valley partition model and demand response model corresponding to every period based on load peak–valley characteristics. Then considering the characteristics of distribution system, the reliability evaluation model considering demand response was established. The example simulation verified that the demand response participated in load reduction strategy could effectively improve the reliability level of the distribution system.

© 2019 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the scientific committee of the 6th International Conference on Power and Energy Systems Engineering (CPESE 2019).

Keywords: Reliability evaluation; Demand response; Distribution system

1. Introduction

Demand response (DR) referred to the user's active adjustment of the power consumption mode according to the electricity price signal or incentive mechanism issued by the power company, which could alleviate the power supply shortage and mentioned in references by Jing et al. [1] and Qingfeng et al. [2]. Demand response could improve the consumption capacity of new energy sources and the reliability of power system, which was mentioned in reference by Meiyu et al. [3].

As the important link of the intelligent electricity process, DR has received extensive attention from scholars at home and abroad. The main research focused on the mechanism analysis of DR, DR modeling for large-scale clean energy consumption, DR benefit assessment and support technologies. The power supply reliability of system considering demand response has received little attention. Reference by Wenjuan et al. [4] proposed the concept of DR virtual power plant and built the price-DR and incentive-DR virtual power plant model, and evaluated the impact of DR uncertainty on low battery expectations. Reference by Hongshan et al. [5] established the tou price

* Corresponding author.

E-mail address: 273580859@qq.com (N. Li).

<https://doi.org/10.1016/j.egyr.2019.11.056>

2352-4847/© 2019 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the scientific committee of the 6th International Conference on Power and Energy Systems Engineering (CPESE 2019).

optimization model, and analyze the load characteristics clustering by load correction link considering power price. At last, the reliability indexes of the distribution system could be gotten. Reference by Ning et al. [6] provided a reliability evaluation method of intelligent power distribution system considering tou power price, which could only consider one type load and had low calculation accuracy.

This paper established the load peak–valley partition model and demand response model corresponding to every period based on load peak–valley characteristics. Then considering the characteristics of distribution system, the reliability evaluation model considering demand response was established. The example simulation verified that the demand response participated in load reduction strategy could effectively improve the reliability level of the distribution system.

2. The demand response model

2.1. Peak and valley time division for load curve

The main purpose of using demand response was to realize peak load shifting by adjusting users' load and using time. The half ladder membership function could be used to determine whether the load point was peak load or valley load in reference by Yi et al. [7]. The probability of each time point in the valley period was A, which was determined by small half ladder membership function. The probability of each time point in the peak period was B, which was determined by big half ladder membership function.

$$A_i = \frac{b - q_i}{b - a} \quad (1)$$

$$B_i = \frac{q_i - a}{b - a} \quad (2)$$

In the above formulas, a was the minimum load in the load set. b was the maximum load in the load set. q_i was the load at time i .

Taking 70% as the division standard, the peak, valley and flat time was n_1 , n_2 and $24 - n_1 - n_2$. In order to reasonably determine the critical point of the peak–valley interval, this paper used two revision strategies. The time numbers in every period should be between 6–10 and the time number in peak period should not more than 8. Every period should not be less than 2 h. Isolated time points could be complicated with adjacent time point sets. Significant indicator S was used to calculate classification effect. When S was bigger, the effect would be better.

$$S = \frac{d_1 + d_2}{\varepsilon_1 + \varepsilon_2 + \varepsilon_3} \quad (3)$$

$$\begin{cases} \varepsilon_n = \max(|M_{ni} - M_{nk}|) \\ d_1 = \min(\min(M_1) - \max(M_2)) \\ d_2 = \min(\min(M_2) - \max(M_3)) \end{cases} \quad (4)$$

In the above formulas, $M_1 - M_3$ expressed the load set of peak period, flat load set and valley load set. M_{ni} , M_{nk} expressed the arbitrary two load in load set M_n .

2.2. The demand response model

The introduction of tou power price and incentive mechanism would lead users to actively reduce electricity consumption. This paper used demand price elasticity $Q(i, k)$ to represent the impact of changes in electricity prices on users. $Q(i, k)$ expressed the relationship between the changed electricity demand at time i and electricity price change rate at time k . Loads at some times could not be transferred to other times, the elastic coefficient was minus. Loads at some times could be transferred to other times, the elastic coefficient was positive.

$$Q(i, k) = \frac{\rho_0(k)}{d_0(k)} \cdot \frac{\partial d(i)}{\partial \rho(i)} \quad (5)$$

In the above formula, ρ pressed electricity price. d expressed electric quantity.

The elastic coefficient had some characteristics showed as below.

$$\begin{cases} Q(i, k) \leq 0, i = k \\ Q(i, k) \geq 0, i \neq k \end{cases} \quad (6)$$

When users participated in demand response, variable quantity of their electricity could be showed as formula (7).

$$\Delta d(i) = d(i) - d_0(i) \quad (7)$$

In the above formula, $d(i)$, $d_0(i)$ expressed users' electricity quantity at the original time and after demand response. $\Delta d(i)$ expressed the load difference. If the reward acquired by cutting unit load at time i was C_i . When the power system had shortage of electricity, the obligations cutting loads of users was $I_C(i)$. The insufficient reduction of cutting loads $I_C(i)$, penalty of unit load was D . The acquired award and penalty of users could be showed as below.

$$I_N(i) = C_i \Delta d(i) \quad (8)$$

$$P_{EN}(i) = D_i \cdot [I_C(i) - \Delta d(i)] \quad (9)$$

Assume that $H(i)$ was users' income at time i when the used electricity was $d(i)$. The users' total revenue M could be showed as below.

$$M = H(i) - d(i)\rho(i) + I_C(i) - P_{EN}(i) \quad (10)$$

In order to maximize users' revenue, the load changing quantity at the demand response starting time i could be showed as below.

$$d(i) = d_0(i) \left[1 + E(i, i) \frac{\Delta \rho(i) + C(i) + D(i)}{\rho_0(i)} \right] \quad (11)$$

In the above formula, $\Delta \rho(i) = \rho(i) - \rho_0(i)$, which expressed the change of electricity price at the demand response starting time i .

Then the load response model for multiple moments could be showed as below.

$$d(i) = d_0(i) \left[1 + \sum_{j=1}^{24} E(i, j) \frac{\Delta \rho(i) + C(i) + D(i)}{\rho_0(i)} \right] \quad (12)$$

3. Reliability evaluation method of distribution network with incentive and electricity price demand response

3.1. The indexes of reliability evaluation for distribution system

The traditional reliability evaluation usually used the annual average load or peak load to evaluate the reliability indexes in long term planning. These could not satisfy real-time requirements for grid dispatchers in the electricity market environment.

Reference by Ning et al. [6] divided the reliability indexes into three types, which were frequency indexes, probability indexes and power quantity indexes.

Power consumption indexes included energy not supplied (ENS) and average energy not supplied (AENS). The power consumption indexes were related with U_i and the users' load level. The power consumption indexes could be showed as below.

$$ENS = \sum_{i=1}^n U_i P_i \quad (13)$$

In the above formula, ENS was the energy not supplied. P_i was the load level at point i . n was the number of load nodes.

Above all, ENS was sensitive to loads variety, which could reflect the impact of demand response on the reliability of distribution system.

3.2. Evaluation method

At time t , the load before demand response was L_t , the cutting load capacity L_t^{LC} and transferring capacity L_t^{LS} could be gotten by optimization. The load after demand response at the same time period could be showed as formula (14).

$$L'_t = L_t - L_t^{LS} + L_t^{LS0} \quad (14)$$

In the above formula, L_t^{LS0} was the load transferred from other time to period t .

The optimized load curve could be gotten by scheduling optimization model, the reliability evaluation of distribution system could be started. This paper used the sequential Monte Carlo simulation method to calculate the real-time reliability index of every time period. Then the influence of load level change caused by demand response on reliability of distribution system could be evaluated. The process of reliability evaluation was showed as Fig. 1.

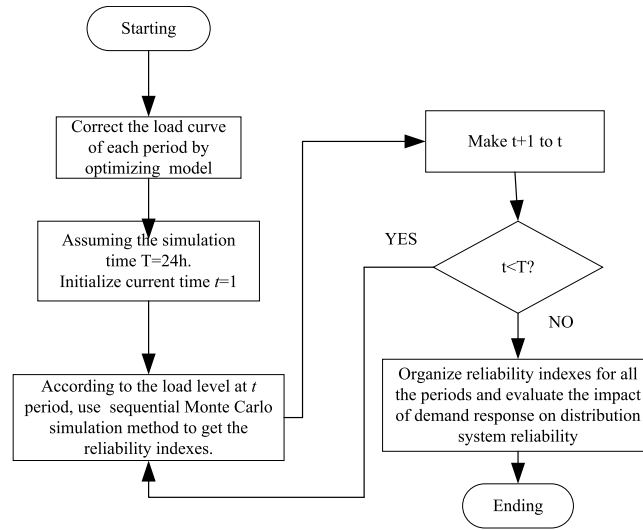


Fig. 1. Reliability evaluation process considering demand response.

4. Example simulation

4.1. The example data

This paper used the main feeder of IEEE RBTS BUS6 system as the simulation example. The example included 2 WTG, 30 lines, 23 load points, 23 distribution transformers, 4 breakers and 9 segment switches. Other system data and reliability parameters could be gotten in reference by Billinton and Jonnavithula [8].

4.2. The demand response result

The result of peak–valley division in different periods was showed in Table 1.

Table 1. The result of peak–valley division for different seasons.

Season	Peak period	Flat period	Valley period
Spring or autumn	10:00–13:00, 18:00–22:00	8:00–10:00, 13:00–18:00, 22:00–24:00	00:00–8:00
Summer	10:00–12:00, 16:00–22:00	8:00–10:00, 12:00–16:00, 22:00–24:00	00:00–8:00
Winter	10:00–13:00, 17:00–22:00	8:00–10:00, 13:00–17:00, 22:00–24:00	00:00–8:00

After introducing demand response, the comparison of typical day load curve for two scenes was showed as Fig. 2. It was easily to know that demand response could improve load fluctuation effectively and realize peak load shifting.

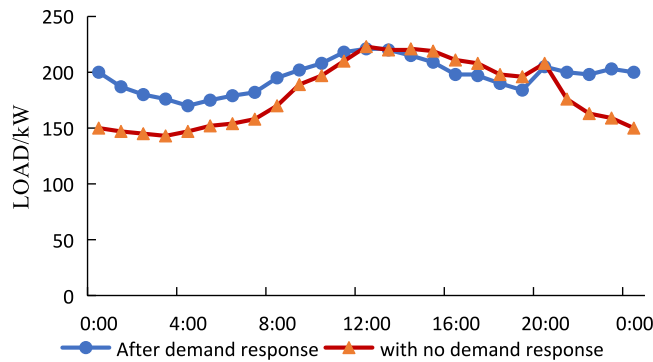


Fig. 2. The typical day load curve of different scenes.

4.3. The result of reliability evaluation

This paper used three scenes to evaluate the system reliability. Scene 1: system had no DG and no demand response. Scene 2: system had DG but no demand response. Scene 3: system had both DG and demand response. The reliability results of load points and system reliability result were showed as Tables 2 and 3.

Table 2. Reliability result of some load points.

Load point	Outage rate (frequency a^{-1})			Average duration of failure (h)		
	Scene 1	Scene 2	Scene 3	Scene 1	Scene 2	Scene 3
Lp1	1.6821	1.6805	1.6778	8.20	8.16	8.09
Lp8	2.0367	1.9841	1.7759	12.65	11.03	9.33
Lp15	1.7998	1.7998	1.7998	11.02	11.02	11.02
LP20	2.5191	2.4688	2.3571	13.26	11.19	8.69

Table 3. The reliability evaluation result of the system.

Scene	SAIFI	SAIDI	ASAI	ENS
1	1.9855	10.286	0.9985	57.4672
2	1.7248	8.337	0.9989	51.2984
3	1.5231	7.925	0.9989	47.3316

Analyzing the reliability evaluation result of different scenes, it was easily to know that various demand response measures could more effectively reduce the peak value of the load curve. So with demand response participating in distribution system operation, the contradiction between power supply and demand could be alleviated which was caused by intermittent renewable energy. The reliability of the distribution system could be improved.

5. Conclusion

By established the load peak–valley division model, this paper could determine the critical point of load peak–valley interval reasonably, and provided the annual load curve division method based on threshold and minimum distance clustering. Then this paper established the scheduling model of demand response and reliability evaluation model. The example simulation result verified that the load peak–valley shifting strategy considering demand response for distribution system could effectively improve the reliability level of system.

References

- [1] Jing Zhang, Wanjun Sun, Ting Wang. Studies on requirements and architecture for automated demand response system. *Proc CSEE* 2015;35(16):4070–6.
- [2] Qingfeng Tang, Nian Liu, Jianhua Zhang. Theory and key problems for automated demand response of user side considering generalized demand side resources. *Power Syst Prot Control* 2014;42(24):138–47.

- [3] Meiyu Hu, Zhijian Hu, Mengmeng Shi. Penetration level and optimize layout of distributed generation based on improved particle swarm optimization algorithm. *Electr Power Constr* 2014;35(12):111–5.
- [4] Wenjuan Niu, Yang Li, Beibei Wang. Demand response based virtual power plant modelling considering uncertainty. *Proc CSEE* 2014;34(22):3630–7.
- [5] Hongshan Zhao, Yingying Wang, Song Chen. Impact of demand response on distribution system reliability. *Autom Electr Power Syst* 2015;39(17):49–55.
- [6] Ning Ding, Junji Wu, Yun Zou. Research of peak and valley time period partition approach and TOU price on DSM. *Autom Electr Power Syst* 2001;25(23):9–12.
- [7] Yi Luo, Gang Wang, Longjun Wang. Reliability evaluation indices for microgrid. *Autom Electr Power Syst* 2013;37(5):9–14.
- [8] Billinton R, Jonnavithula S. A test system for teaching overall power system reliability assessment. *IEEE Trans Power Syst* 1996;11(4):1670–6.