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A Review of Distributed PV Operation Analysis and Demand Response Research

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Abstract. The large-scale access of the distributed photovoltaic power supply to the grid will bring great challenge to the safe operation of power grid, thus adversely affecting the further development of distributed photovoltaic. First of all, from the aspects of structure, power quality, network loss and relay protection, this paper summarizes the influence of distributed photovoltaic system on distribution network. Secondly, the distributed photovoltaic output is summarized and summarized from two aspects of distributed photovoltaic output performance analysis and output forecast. In addition, from the perspective of photovoltaic user demand response can improve the photovoltaic extinction rate, this paper also combs the analysis and research of PV user demand response modelling and electricity price mechanism. Finally, some suggestions on the key areas for future research are put up.

1. Introduction

The development prospect of distributed photovoltaic power generation is broad [1], it advocates the spontaneous use of electricity, the rest of the internet, there is no step-up and long-distance transportation problem, directly facing the terminal power consumers[2], in the power market reform and energy-saving emission reduction situation, has got more and more attention and development. With the increase of the distributed PV network capacity, the safe and stable operation of the power system will be influenced by the non-negligible [3]. The accurate characteristic analysis and output prediction of distributed PV are the important foundation to solve these problems and ensure the safe operation of the power grid [4]. At the same time, a lot of researches have been done on demand side participation in distribution network, the purpose of which is to adjust shifting and increase PV extinction rate by using demand response of PV users [5-9].

Based on the influence of photovoltaic power grid on distribution network, this paper collated the research of PV power generation characteristics analysis and output prediction, and then it has further combed the research on PV user demand response, which has provided some reference for readers.

2. The Influence of Distributed Photovoltaic on Distributed Network

Due to the influence of solar radiation intensity, the output of PV power has a strong randomness and intermittence, which has important influence on power quality, voltage fluctuation, economy and relay protection [10-14]. First of all, the grid-connected distributed photovoltaic power system changes the distribution network structure, and when not coordinated with the load distribution grid, it will increase the difficulty of the voltage regulation of the distribution grid [15-16]. Secondly, the large-capacity photovoltaic grid-connected under different operating modes will greatly influence the power flow size and direction of distribution network, thus causing the change of voltage distribution [17-19] and network loss [20-21], and changing the economy. In addition, the distribution of distributed photovoltaic power supply network, will inevitably provide a certain short-circuit current to short-circuit point, which may have an impact on the distribution automation fault location [22-24].

The above research shows that large-scale grid-connected photovoltaic power supply will bring power quality problems, affect the stability of power grid, and cause economic loss to power users of distribution network, and endanger the safe and reliable operation of PV system. Therefore, it is necessary to accurately analyse and forecast the output characteristics of distributed photovoltaic system, and put forward a reliable countermeasure of eliminating the solar energy to reduce the impact of distributed photovoltaic on grid.

3. Analysis and Prediction of Distributed PV Output Characteristics

Due to the randomness and volatility of photovoltaic power generation, a large number of photovoltaic power grids will not only increase the system net load fluctuation range, but also reduce the accuracy of load forecasting, and make the fluctuation of net load of system more uncertain. Accurate analysis of PV output characteristics and generation forecasting will have an important impact on daily power generation scheduling and power system operation planning.

3.1. Analysis of Distributed PV Output Characteristics

The analysis of the distributed PV output characteristics mainly aims at the fluctuation of PV power in different time periods and different conditions, and the weather factors such as sunshine and temperature, and the structure and installation mode of PV system are also the important factors that influence the output.

For the study of volatility, literature [25-26] studied the effects of cloud movement and different configuration combinations of photovoltaic arrays on photovoltaic output power. Literature [27] presented a method to extract the random components of photovoltaic output, and accurately described the continuity of PV output fluctuation. Literature [28] presented a method for analyzing the stochastic characteristics of the output of photovoltaic power station. The deterministic factors of PV power generation and the uncertain factors were separated. The stochastic characteristics of PV output occlusion factors were studied from the aspects of probability distribution and fluctuation characteristics, and the spatial correlation of photovoltaic output was analysed by means of empirical analysis. Literature [29] defined the photovoltaic output state according to the PV output operating point and its fluctuation limit value, then it quantitatively studied the time length of PV power maintenance in a certain state, and put forward the concept of the duration distribution of PV power.

For PV System Research, literature [30] took the distributed maximum power point tracking (DMPPT) photovoltaic system as the research object, aiming at the optimization problem of multiple distributed maximum power tracking module networks, analysed the structure of multiple PV modules cascade based on the static output characteristics of the system, and presented a new distributed maximum power point tracking PV system structure, besides, the output characteristics of photovoltaic under this structure were analysed.

3.2. Distributed Photovoltaic Output Forecast

At present, the main principle of photovoltaic power forecasting is based on the future weather conditions combined with the solar radiation and photovoltaic panel layout of the solar panels to receive radiation prediction, and then estimate the power of photovoltaic panels [30].

From the point of view of weather condition and solar radiation law, literature [31] used the autoregressive sliding average model to construct the stochastic time series of the PV output sequence, and gave a consideration to the correlation of the output sequence of the multi power station by using the characteristics of the autoregressive sliding average mathematical model. Literature [32] put forward a systematic method to optimize the operation of the feeder and to ensure the voltage quality, to determine the photovoltaic active and reactive power output of residential roofs. Literature [33] used the framework of stochastic differential equations to predict the probability of solar irradiation. Literature [34] first predicted the probability distribution of the hourly clear sky index through Bayesian autoregressive time series model, and then calculated the probability distribution of PV output by random sampling of the clear sky index by Monte Carlo simulation. Literature [35] used the copula function to model the joint probability distribution of PV actual output and point prediction, and realized the estimation of conditional probability distribution of the corresponding photovoltaic actual output by any point prediction. Literature [36] in view of the timing and randomness of PV power generation, the output model of PV power system was improved by stratified sampling of weather type sampling and equipment outage probability.

From the point of view of other distributed power sources research, literature [37] used the copula theory of stochastic mathematics to set up the conditional prediction error model of PV power generation based on the wind power forecasting error model. From the point of view of power network planning. Literature [38-40] made a deep study on the distributed Photovoltaic capacity prediction and evaluation in the planning area, and put forward a method of distributed photovoltaic generation and spatial forecasting for active distribution network planning.

4. PV User Demand Response

From the above analysis, distributed photovoltaic power grid will bring a variety of adverse effects on PV, on the basis of accurate analysis and prediction of photovoltaic output, the demand response in PV user group can improve the self-elimination rate of PV power and effectively adjust the influence of PV output power on power grid [41].

In the research of demand response modeling of PV users, based on PV generation curve and demand response characteristics, literature [42] established the real-time pricing model and the user's price response model. Combined with real-time pricing and user response model, the realization method and process of load transfer were constructed, which encouraged the user to transfer the transfer load to the photovoltaic power generation and increase the net load value of PV output period. Under the peak-Valley time-sharing price, literature [43] constructed a multiple-time tariff response model based on the energy price elasticity matrix, and put forward the strategy of energy charging and discharging and the optimal operation of optical storage micro-network. Literature [44] took the load curve minus the equivalent load curve obtained from the PV curve as the optimal object of the time-sharing price, and established and solved the optimization model of the peak-Valley time-sharing electricity price. Based on the characteristics of users' power, literature [45-46] constructed a multi buyer-seller pattern within the PV user group, combined with China's distributed PV Internet policy, and put forward a demand-side response model based on game theory, and proved that the game problem has a unique Nash equilibrium strategy. Literature [47] presented an internal price model based on photovoltaic power supply and demand ratio (SDR). Based on the consideration of economy and comfort, the utility cost model of user participating in demand response was put forward.

In the research of PV user price mechanism, literature [48] studied the user's response to the price, and the marginal cost fixed price or the fixed price of the given rule was to develop the optimal pricing strategy by collecting the power generation and load of the whole cluster. Literature [49] studied the optimal operation of photovoltaic micro-power grids containing energy storage. Through the relationship between supply and demand in the micro-grid, this paper put forward the two pricing strategies based on the pricing rules, and gave two kinds of game models. Literature [50] for the Peak-Valley time-sharing electricity price and the ladder electricity price 2 kinds of mainstream electricity purchase policy, taking account of the factors such as the profit of electricity sales, the cost of buying electricity and government subsidy, the optimal dispatching model of grid-connected PV power system was established, which was based on the distribution ratio of surplus to the optimal variable and the user benefit. Literature [51-52] calculated the economical reasonable PV power price by establishing the net present value model, then according to the difference of the solar resource endowment and the system construction condition in the domestic area, changed the electricity generation and the installment cost in the model to set up the PV network guiding price.

The above research from the net present value, the game, the optimization and so on launches, has carried on the comprehensive and the detailed analysis to the PV user demand response modelling and the electricity price mechanism, has the important reference significance to the future research. However, the analysis of the response behavior characteristics of PV users is not deep enough to reflect the dynamic relationship between the electricity price mechanism and the user's power behaviour.

5. Conclusion

This paper sums up the current research situation from the aspects of the impact of large-scale grid-connected photovoltaic power supply on power grid, analysis and prediction of PV output characteristics and demand response of PV users. At present, most of the literatures on PV users' demand response are based on the research of ordinary resident users, and the characteristics of PV users are not detailed and thorough enough, some models fail to consider the actual installation and operation of the distributed PV system. Then the paper offers the suggestions on the research point, to provide reference for the further study.

1) In the study of distributed photovoltaic grid-connected, we should consider the safe and stable operation of power grid, and further research on grid-connected detection and grid-connected capacity control.
2) In the study of PV user demand response, we should deeply analyze the user configuration of PV demand response behavior, to achieve the dynamic correlation with electricity price.
3) We should discuss the influence of PV users' consumption ability, economic level, and time and seasons on the usage of photovoltaic users, to make the research more realistic.
4) We can further discuss the selection behavior of the user under the demand of response mechanism when combining PV with energy storage.

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References

[1] Sicheng. Current situation and development trend of distributed photovoltaic power generation policy [J]. Solar energy, 2013 (8): 8-19.
[2] Bo, Liaoqiangqiang, Liu, etc. economic analysis of the hybrid system of distributed photovoltaic energy storage battery [J]. Power construction, 2016, 37 (8): 102-107.
[3] Chang Jiale. The influence of distributed photovoltaic power supply on distribution network and the study of grid-connected planning [D]. Power, 2016.
[4] Wang Hongkun, Greid, Li Hongwei, and so on. A review of the characteristic analysis and prediction methods of distributed photovoltaic power generation [J]. Power construction, 2017, 38 (7): 1-9.
[5] Kim T, Kim S, Shin D, et al. Design and Implementation of an Open, Interoperable Automated Demand Response Infrastructure[J]. Lawrence Berkeley National Laboratory, 2008, 12(4):537-550.
[6] Gao Wei, Liang Sweet, Li. A review of the theory and practice of automatic demand response [J]. Power Grid technology, 2014, 38 (2): 352-359.
[7] Shenwancheng, Zhang, di Hongyu, etc. application of immune optimization algorithm based on dynamic antibody memory in automatic demand response [J]. Journal of China Electrical Engineering, 2014, 34 (25): 4199-4206.
[8] Wang Dongjong. The theory and empirical Study of DSM response [D]. Power (Beijing), 2011.

[9] Zeng Ming, Han Xu, Rae. Support mechanism of demand side response for active distribution network operation [J]. Power construction, 2015, 36 (1): 110-114.
[10] Huang, Dong, Requin, and so on. Comprehensive impact analysis of large capacity distributed PV grid on distribution network [J]. Journal of power system and automation, 2016, 28 (11): 44-49.
[11] Requin, Li Hawk, Luzehan, etc. distributed generation technology and its influence on power system [J]. Southern Power grid Technology, 2011, 05 (4): 46-50.
[12] Yu Lei, Xu Lili, Zhou Xin. The influence of distributed photovoltaic power generation on distribution network and its countermeasures [J]. North China Power Technology, 2013 (10): 13-17.
[13] Tong, Lancenlin. The influence of distributed generation on distribution network [J]. East China Power, 2010, 38 (7): 1038-1039.
[14] Zhu Zhongli, Ying, Cao Wei, and so on. The impact of large-scale distributed access on power grid [J]. East China Power, 2012 (12): 2224-2227.
[15] Miuliheng. Study on the effect of distributed PV access on the steady state operation of distribution network [D]. Power (Beijing), power, 2015.
[16] Liqingfeng. Effect of distributed photovoltaic system on power quality of distribution network [D]. Power, 2016.
[17] Li Yaling, Weile, Zhao Jingtao, and so on. The effect of distributed PV system on distribution network voltage [J]. Power technology, 2016, 40 (6): 1257-1259.
[18] Wang Zhiqun, Zhu Shoujien, double happiness, etc. effect of distributed generation on voltage distribution of distribution network [J]. Power system Automation, 2004, 28 (16): 56-60.
[19] Xu Xiaoyan, Sui Fai, Liu Chun, etc. the influence of distributed photovoltaic on distribution network voltage and the solution of voltage limit [J]. Power grid Technology, 2010 (10): 140-146.
[20] Ho, He Huachen, Li. Influence of distributed PV access on network loss of distribution network [J]. Modern electronic technology, 2014 (6): 158-162.
[21] Li, Peng, clear, and so on. The power flow calculation of distributed grid connection [J]. Power system Protection and control, 2009, 37 (17): 78-81.
[22] Lin Tao, Liu Jian, Tong Xiangqian and so on. Simulation analysis of the effect of distributed photovoltaic power supply on short-circuit current of distribution network [J]. Power grid Technology, 2013, 37 (8): 2080-2085.
[23] Kong Xianping, Jangchul, Yin Xiangen, etc. research on fault current characteristics and fault analysis method of power system with inverse variant distributed power supply [J]. Journal of China Electrical Engineering, 2013 (34): 65-74.
[24] Mrs. Liu, Zhang Xiaoqing, Tong Xiangqian, and so on. Fault location of distribution network with distributed power supply [J]. Power system Automation, 2013, 37 (2): 36-42.
[25] Lappalainen K, Valkealahti S. Output power variation of different PV array configurations during irradiance transitions caused by moving clouds[J]. Applied Energy, 2017, 190:902-910.
[26] Belhaouas N, Cheikh M S A, Agathoklis P, et al. PV array power output maximization under partial shading using new shifted PV array arrangements[J]. Applied Energy, 2017, 187:326-337.
[27] Zhao Liang, Li Jiaming, Aixiao, et. Analysis of the stochastic components extraction and statistical characteristics of PV output [J]. Power system automation, 2017, 41 (1): 48-56.
[28] Xi, Kang Chongqing, Ning, etc. analysis of the medium and long term stochastic characteristics of solar photovoltaic generation [J]. Power system Automation, 2014, 38 (6): 6-13.
[29] Li Jiaming, Aixiao, Wen Jingyu, et. Quantitative analysis of the probability distribution of PV power duration characteristics [J]. Power system automation, 2017, 41 (6): 30-36.
[30] Wang, Kong Pengju, Fred, etc. analysis of output characteristics of PV system based on distributed maximum power tracking [J]. Journal of Electrotechnical Technology, 2015, 30 (24): 127-134.

[31] Klöckl B, Papaefthymiou G. Multivariate time series models for studies on stochastic generators in power systems[J]. Electric Power Systems Research, 2010, 80(3):265-276.
[32] Dall'Anese E, Dhople S V, Giannakis G B. Optimal dispatch of photovoltaic inverters in residential distribution systems[C]// Pes General Meeting | Conference & Exposition. IEEE, 2014:1-1.
[33] Iversen E B, Morales J M, Møller J K, et al. Probabilistic forecasts of solar irradiance using stochastic differential equations[J]. Environmetrics, 2014, 25(3):152–164.
[34] Bracale A, Caramia P, Carpinelli G, et al. A Bayesian Method for Short-Term Probabilistic Forecasting of Photovoltaic Generation in Smart Grid Operation and Control[J]. Energies, 2013, 6(2):733-747.
[35] Chang, Ning, Kang Chongqing, and so on. The conditional prediction error probability distribution estimation method for PV generation output [J]. Power system automation, 2015 (16): 8-15.
[36] Wang Beautiful, Wu Zechen, Qu Chong. Reliability analysis and confidence capacity calculation of photovoltaic power system [J]. Journal of China Electrical Engineering, 2014, 34 (1): 15-21.
[37] Zhang N, Kang C, Xia Q, et al. Modeling Conditional Forecast Error for Wind Power in Generation Scheduling[J]. IEEE Transactions on Power Systems, 2014, 29(3):1316-1324.
[38] Fu Yang, Tianzan, Li Zhenkun, Diliang, Jin Shanhong, Zhang Jingwei. Distributed photovoltaic spatial-temporal distribution prediction considering spatial capacity saturation [J/ol]. Power grid technology: 1-8. (2017-07-04).
[39] Villavicencio J, Melo J D, Feltrin A P. Estimation of photovoltaic potential on residential rooftops using empirical Bayesian estimator[C]// Innovative Smart Grid Technologies Latin America. IEEE, 2016:242-247.
[40] Rowley P, Leicester P, Palmer D, et al. Multi-domain analysis of photovoltaic impacts via integrated spatial and probabilistic modelling[J]. Renewable Power Generation Iet, 2015, 9(5):424-431.
[41] Ding Z, Lee W J, Wang J. Stochastic Resource Planning Strategy to Improve the Efficiency of Microgrid Operation[J]. IEEE Transactions on Industry Applications, 2015, 51(3):1978-1986.
[42] Shi Lei, Hu Jianzhao, Han Shengfeng, et. Study on the strategy of increasing the power price incentive load transfer for PV grid-connected penetration [J]. Power system protection and control, 2016, 44 (23): 153-157.
[43] Zhou, Fan Wei, Liu Nian, and so on. Multi-Objective capacity optimization configuration of PV micro-network energy storage system based on demand response [J]. Power grid technology, 2016, 40 (6): 1709-1716.
[44] Fan Wenfei, Feng Fei, Wang Delin. Study on optimization strategy of time-sharing electricity price after PV power access network [J]. Electrical switches, 2016, 54 (4): 46-50.
[45] Wang, Liu Nian, Cheng Minhao, etc. the optimal pricing model of PV user group based on Stackelberg game [J]. Power system automation, 2017, 41 (12): 146-153.
[46] Mary, Liu Nian, Jianhua, etc. optimal operation model of PV user Group under Automatic demand response mode [J]. Journal of China Electrical Engineering, 2016, 36 (13): 3422-3432.
[47] Liu Nian, Wang, Requin. Power sharing and demand response model of PV user Group in market mode [J]. Power system automation, 2016, 40 (16): 49-55.
[48] Ding Z, Lee W J, Wang J. Stochastic Resource Planning Strategy to Improve the Efficiency of Microgrid Operation[J]. IEEE Transactions on Industry Applications, 2015, 51(3):1978-1986.
[49] Maity I, Rao S. Simulation and Pricing Mechanism Analysis of a Solar-Powered Electrical Microgrid[J]. IEEE Systems Journal, 2010, 4(3):275-284.
[50] Ma Lin, Zhang Shirong. Optimal operation of home-connected PV power system under time-sharing price/step electricity price [J]. Power grid technology, 2016, 40 (3): 819-825.
[51] Rigter J, Vidican G. Cost and optimal feed-in tariff for small scale photovoltaic systems in China[J]. Energy Policy, 2010, 38(11):6989-7000.

IOP Conf. Series: Materials Science and Engineering **366** (2018) 012055 doi:10.1088/1757-899X/366/1/012055

[52] Chan Wei. Research on PV power Price and its policy [D]. East China University of Technology, 2013.