

Degraded output characteristic at atmospheric air pollution and economy analysis of PV power system: A case study

Abstract. This paper gives the experiment data of atmospheric air pollution of a PV system located in Taiyuan. The results show that the dust fall decrease the output efficiency of PV module and the different dust thickness result in the partially shaded of PV module and the multi-peak point. PV surface cleaning in fixed period is very important to improve the output efficiency of PV power system. Then the economy benefit of a supposed PV power station is analyzed, which reveals the correlation of employed worker number and time interval of PV cleaning and increasing benefit.

Streszczenie. Przedstawiono dane eksperymentalne zanieczyszczenia atmosfery w obecności systemu fotowoltaicznego w miejscowości Taiyuan. Potwierdzono, że opad kurzu pogarsza skuteczność modułów fotowoltaicznych przy czym pogorszenie zależy od grubości warstwy kurzu. (Degradacja skuteczności systemu fotowoltaicznego powodowana zanieczyszczeniami atmosfery)

Keywords: air pollution; PV power system; experimental measurements.

Słowa kluczowe: system fotowoltaiczny, zanieczyszczenie atmosfery.

Introduction

At present, China has become the second largest energy consumption country in the world. The total consumption amount of coal and oil are more than 2.74 and 0.36 billion tons in 2008, respectively, and natural gas is about 80.7 billion m^3 [1]. The coal in the total energy structure has a large share of 70% in the past 30 years, which has brought a series of environmental problem such as greenhouse air emissions, acid rain, soil pollution, and so on. The total pollution loss accounts for 10% of Chinese Gross Domestic Product over the past 10 years [2]. The inappropriate energy supply structure in China must be changed to realize the sustainable development of country and society in future [3]. Chinese central government and local governments have realized the serious question, and the application of renewable resources has come into the rapid development stage to improve current inappropriate energy structure. The solar energy resource in China is abundant, and some large scale photovoltaic (PV) power stations have been established in western remote district, and the total installed amount of every power station is normally more than 100MW [4]. The installed amounts of PV power in 2020 will more than 15,000MW, which has a share of 1% in the total power system. With the increasing consider of PV power in the whole world, and some advanced technologies and control methods have been used in PV power domain, such as maximum power point tracking (MPPT) method [5-7], sun tracking technology [8], hybrid solar-wind power system [9-10], and integrated PV/Solar thermal collector system [11-14], etc.

At present, the price of PV module in China is very costly, which is about 2~3 \$/W, and the actual output efficiency in real engineering is less than 15%. And most of solar radiation energy converts thermal energy, and the temperature of PV panel is increasing and the output efficiency is decreasing. Therefore, in order to improve the output characteristic of PV array, many MPPT algorithms and control schemes of PV generate system have been proposed in the literature, such as perturbation and observation method, incremental conductance method, Fuzzy logic method, and Artificial neural network method, etc. Furthermore, the current-voltage and power-voltage characteristics of large scale PV power system at partial shading are characterized by multiple steps and peaks, and rapidly changing shadow conditions increase the difficulty of MPPT. It is very hard to identify the global maximum power point (MPP) because multiple local peaks exist, and their locations fluctuate rapidly corresponding to the changing

shading conditions [5-7]. So a high efficiency MPPT is important to increase the output of the costly PV power system. But the most research achievements pay close attention to gain the real maximum power point by using PO, IC, or improved method. But there are a little scholar considers the degradation output characteristic of PV power system under atmospheric air pollution condition [15-18].



(a)



(b)

Fig.1. Urban air pollution in China (Source: [20-21])

At present, atmosphere air is well known to be considerably aggravated by infectious suspended particles. Primary sources comprise both human and natural processes [15]. And the atmosphere air in China is considerably aggravated which is more than Europe, America, and Oceania, etc [19-21]. According to National Aeronautics and Space Administration (NASA) satellite data, the China's air quality is worst as compared with other parts

of the world. Eastern industrial zone in China has the largest concentration of suspended particles. This is not the residents there what good omen. And if you're in the eastern areas and want to breathe the fresh air will have to flee [19]. According to the statistics data, there are more than 100 cities is considerably aggravated pollution, such as Taiyuan, Lanzhou, and Linfen, and so on. At present, Chinese urban air pollution has very serious, which has led to a series of health question such as lung cancer and respiratory system disease. The current urban air quality in China can be seen in Fig.1. For an actual example, when I still an undergraduate in 1995, the colour of first snow in Taiyuan is black, and there are a lot of coal powder exists in the white snow. Hence, the suspended particles amount of atmosphere air in China is more than other area of the world. It is very important to consider the Characteristics and distribution and size of suspended particles in atmosphere air in order to improve the output efficiency of PV power system in China. Unfortunately, the suspended particles in China did not be considered by scholar to gain maximum output power of PV.

The article presents a case of PV power system which considers the atmosphere air and dust to improve the output performance and reduce the loss of PV system and arouse the regard of engineers in China. And the economy analysis is discussed to realize the maximum benefit of a supposed PV power station.

Site and surrounding environment of project

Table 1. Main atmospheric pollutants data statistics results in Taiyuan from 2000 to 2008 (Source: [22])

Year	PM_{10} (mg/m^3)	SO_2 (mg/m^3)	NO_2 (mg/m^3)
2000	0.401	0.200	0.051
2001	0.206	0.153	0.044
2002	0.177	0.129	0.037
2003	0.172	0.099	0.030
2004	0.164	0.079	0.022
2005	0.139	0.077	0.020
2006	0.142	0.066	0.025
2007	0.122	0.064	0.027
2008	0.094	0.073	0.021
Air quality standards in China	0.15	0.15	0.12



Fig.2. Surrounding environment of project

Taiyuan is the capital of Shanxi province, which located in the central area of China. There are billions of tons coal contains in the underground, and the annual yield of coal is more than 0.5 billion tons over the past ten years. So there are thousands of tons coal is transported to other area by using the coal cars and trains. Taiyuan is the most serious air pollution in Chinese city, and the main atmospheric

pollutants data from 2000 to 2008 can be seen from Table.1. Taiyuan University of science & technology located in Waliu road of Wanbolin district, Taiyuan city, and the amount every day of traffic flow is more than 2000, here, there are more than 300 coal cars and trains pass the road every day, and the surrounding environment is very wicked and the dust is very much, which can be seen from Fig.2. The PV system is established in the top of building, and the building is neighbouring the road, and the height of building is about 30 meters. Certainly, the surface of PV modules after cleaning has thick dust after a few days. The degradation of PV output efficiency is very aggravated. The accumulation characteristic of ash must be considered to increase the output efficiency of PV system.

Experimental procedure



Fig.3.Experimental PV modules

It is well known that the PV can convert the solar radiation energy to electricity, and the highest convert efficiency of PV has more than 30% at present, certainly, the normally efficiency of PV of actual engineering is less than 15%, due to the increasing temperature of PV panel and the covered dust. According to existing published work, the covered dust of PV panel is considered little to compare with the increasing temperature. With the more and more severe air pollution in the urban environment, due to high population densities and increased economic and industrial activities. The dust characteristic research of PV panel is very important to improve the output efficiency.

An easy testing is put into effect by using six PV modules with maximum output power of 1kW and open circuit voltage of 120V and short circuit current of 11.6A and optimal output voltage of 96V and output current of 10.4A at $25^{\circ}C$ and $1kW/m^2$, as shown in Fig.3. The maximum output power, optimal output voltage and current of sole PV module is about 167W, 33V and 5A, respectively. The effects of dust accumulation on PVs' surface have been experimentally investigated by El-Shobokshy and Hussein in order to find the correlation between dust deposition density and the short circuit current and power output variation of PV module. In our test, a Chinese case is described to explain the different characteristics of covered dust. The clean PV modules are divided into three groups, and every group has a clean PV module and a naturally polluted PV module, and the tilt angle of first, second and third group is 90° , 45° and 0° , respectively. Certainly, the direction of PV modules is toward South.

The experimental testing is implemented in November, 2011. Firstly, six PV modules are cleaned, and the batteries to be drained up by using a consumptive load. Secondly, three groups were fixed in different tilt angles, and one PV module of each group is chose, which is cleaned every day. Thirdly, the experimental procedure was carried out under

clear sky conditions while 10 measurements were recorded within the time period of one day (approx. 1 measurement per hour during the day).

Experimental data discussion

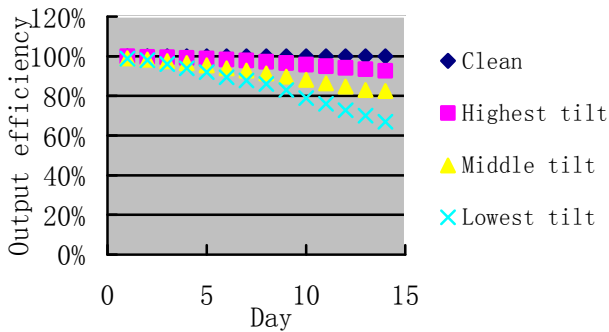


Fig.4. Output efficiency at different experimental tilt

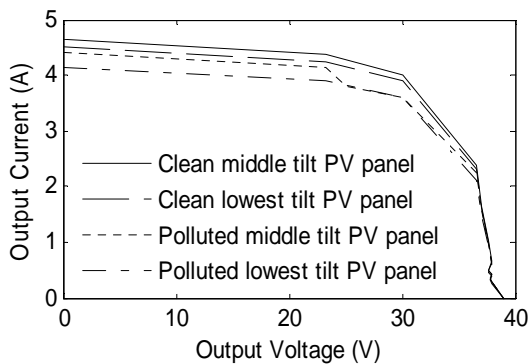


Fig.5. Experimental data at different tilt

As shown in Fig.4, the output efficiency of natural polluted PV module is decreasing with the time to compare with the clean PV module at same tilt. After two week, the power less of naturally polluted PV module of first group which has higher tilt angle is about 7% as compare with the clean PV module of first group, and the power less of second group which has a middle tilt angle is more than 15% as compare with the clean PV module of second group at naturally polluted, and the power less of third group which has the lowest tilt angle is about 30% as compare with the clean PV module of third group. The accumulation of suspended particles has a big effect to decrease the output efficiency of costly PV module. And installed different tilt of PV module has different effect to the output efficient as can be seen from Fig.5. Generally, large tilt has small effect by the accumulation of ash. Certainly, the maximum tilt can not more than 90° . As a conclusion, the atmosphere air of established project is worse than the most area located in Europe, America, and Oceania, etc. Furthermore, the PV power station should pay more attention to the infectious suspended particles than other area of the world. In order to increase the output efficiency, it is important to clean the ash of PV surface at fixed period. For example, the output efficiency loss of middle tilt PV module is about 5% at fifth day, and the output efficiency loss of lowest tilt PV module is about 8%. So the clean time of PV surface at fixed period is different based on different installed tilt, and the clean time at fixed period will decrease with the increasing of installed tilt.

Other discovery, as mention above, the density of suspended particles of atmosphere air in Taiyuan is very large, which induces a large amount of deposition of dust, and the thickness of deposition of dust on PV surface is

different based on different height and tilt as can be seen in Fig.6. Generally, with the increasing of height, the dust thickness is reduced. So one PV module has different solar radiation and temperature, which induces that the PV output characteristic is more nonlinear and exist multi-peak point. The output performance of PV under partially shading conditions has been published in many literatures [5-7], and the degraded output efficiency is inevitable. And the most literatures introduce the large PV array with many series-parallel connections of PV modules. But the sole partially shaded PV module is not been considered. The output characteristic of sole PV module can be seen in Fig.5. The dust thickness of low tilt PV module is approximately equal, but the thickness of middle tilt is different based on different height of PV module as can be seen in Fig.6. So the clean PV surface is necessary to improve the output performance of sole PV module.



Fig.6. Naturally polluted PV module and different dust thickness

Economy analysis

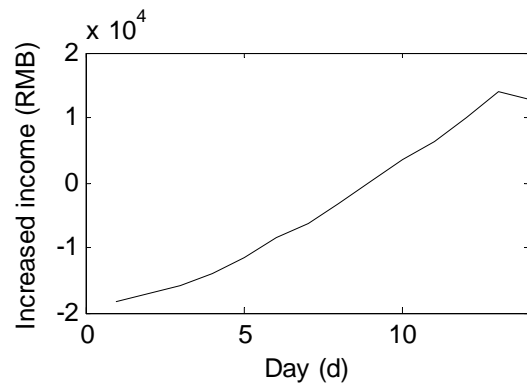


Fig.7. Economy analysis of large scale PV power station

Certainly, a certain number workers are hired for PV surface cleaning is necessary, and some other cost is consumed such as water, detergent, and cloth, etc. The optimal correlation between worker number and economy benefits is very important to improve the economy benefit of PV power station. The economic benefit maximization theory is considered to be the implemented criteria for employed number of workers and fixed period of PV surface cleaning. A 100MW PV array is supposed in the section, and the salary of a worker is about 3000 RMB per month, the average clean amount of a worker is about 1200kW per day, and the other cost of per kW of PV surface cleaning is about 0.1 RMB, and the average maximum solar radiation time is 3.5 hours, and the sun tracking technology is not be considered. The maximum time interval of PV surface cleaning is two weeks. Furthermore, the current grid price of

electric from PV power station in China is about 1 RMB/kWh, and one dollar is about equal to 6.35 RMB.

The experimental data as can be seen in Fig.4 is used in the economy analysis, here, the changing of middle tilt PV is used in this paper. The basic idea is that the employed workers are used to clean PV surface and improve output efficiency of PV array. And, the more number of employed workers, the shorter time interval of PV surface cleaning, certainly, the more salary is necessary. Inversely, the fewer workers are hired, the less salary is paid, certainly, the longer time interval of PV surface cleaning, and the worse output efficiency of PV system. So there are a balance between employed number and output efficiency, which is based on the maximum economy benefit of PV system. As shown in Fig.7, the time interval is more shorted, which need more employed number of worker, and the economy benefit is not best. In this case, the best time interval is 13 days, and the employed number of worker is six, and the increasing benefit at two weeks is about 2,205 dollars (about 14,000 RMB), and the annual increasing benefit is about 57,480 dollars (about 365,000 RMB). The correlation of time interval and employed number and increasing benefit in two weeks can be seen in Table.2. In a word, the PV surface cleaning is necessary to improve the economy benefit of costly PV power system, there do exist a best time interval of PV surface cleaning based on different atmosphere air quality.

Table 2. The correlation of time interval and employed number and increasing benefit (unit: one thousand dollars)

Time interval	1	2	3	4	5	6	7
Worker number	83	42	28	21	17	14	12
Increasing benefit	-2.9	-2.7	-2.5	-2.1	-1.8	-1.3	-1.0
Time interval	8	9	10	11	12	13	14
Worker number	10	9	8	8	7	6	6
Increasing benefit	-0.5	0	0.5	1.0	1.6	2.2	2.0

Conclusion

As a conclusion, the atmosphere air in China is considerably aggravated which is more than Europe, America, and Oceania, etc. So the time interval of PV surface cleaning is shorter than other area. Then the experimental data of middle tilt PV module is used to analyze the economy benefit of costly PV power station, there are exist a best time interval of PV surface cleaning based on maximum annual economy benefit.

Acknowledgments: this work was supported by the Program for the Industrialization of the High and New Technology of Shanxi province (NO: 2010016), Youth Science Foundation of Shanxi province (NO: 2011021014-2), Doctor Fund of Taiyuan University of Science & Technology (NO: 20122018).

REFERENCES

- [1] National Bureau of Statistics of China, 2008. Statistics report of country economy and society development in 2009. http://www.stats.gov.cn/tjgb/ndtjgb/qgndtjgb/t20090226_40254_0710.htm.
- [2] CCTV, The Great Divide of environmental protection: the loss due to pollution in China each year 10% of GDP, 2007. <http://finance.cctv.com/20070319/100794.shtml>.
- [3] Chinese Development and Innovation Committee (CDIC), 2008. <http://finance.sina.com.cn/roll/20080409/02202131646.shtml>.
- [4] Chinanews.com, Maximum PV power projects in dunhuang is constructed, in Gansu province, 2011. <http://www.chinanews.com/ny/2011/06-13/3108324.shtml>
- [5] Alajmi, Bader N., Ahmed, Khaled H., Finney, Stephen J., and Barry W. Williams, Fuzzy-Logic-Control Approach of a Modified Hill-Climbing Method for Maximum Power Point in

Microgrid Standalone Photovoltaic System, IEEE TRANSACTIONS, POWER ELECTRONICS, 26(2011), No.4, 1022-1030.

- [6] Syafaruddin, Karatepe E., Hiyama, T., Artificial neural network-polar coordinated fuzzy controller based maximum power point tracking control under partially shaded conditions, IET Renewable Power Generation, 3(2009), No.2, 239-253.
- [7] Carannante, G., Fraddanno, C., Pagano, M., and Piegari, L., Experimental performance of MPPT algorithm for photovoltaic sources subject to inhomogeneous insolation, IEEE Transactions, Ind. Electron., 56(2009), No.11, 4374-4380.
- [8] Essam A., Mohammed A., Ali A., and Salah A., Cylindrical Solar Cooker with Automatic Two Axes Sun Tracking System, Jordan Journal of Mechanical and Industrial Engineering, 4(2010), No.4, 477-486.
- [9] Yang H., Zhou W., and Lu L., et al, Optimal sizing method for stand-alone hybrid solar-wind system with LPSP technology by using genetic algorithm, Solar Energy, 82(2008), no. 4, 354-367.
- [10] Diaf S., Diaf D., and Belhamel M., et al, A methodology for optimal sizing of autonomous hybrid PV/wind system, Energy Policy, 35(2007), no. 11, 5708-5718.
- [11] Ibrahim, A., Othman, M.Y., Ruslan, M.H., and Mat, S., et al, Recent advances in flat plate photovoltaic/thermal (PV/T) solar collectors, Renewable and sustainable energy reviews, 15(2011), No.1, 352-365.
- [12] Solanki, S.C., Dubey, S., Tiwari, A., Indoor simulation and testing of photovoltaic thermal (PV/T) air collectors, Applied energy, 86(2009), No.11, 2421-2428.
- [13] Pantic, S., Candanedo, L., Athienitis, A.K., Modeling of energy performance of a house with three configurations of building-integrated photovoltaic/thermal systems, Energy and Buildings, 42(2010), No.10, 1779-1789.
- [14] Pei, G., Fu, H., Zhang, T., and Ji, J., A numerical and experimental study on a heat pipe PV/T system, Solar energy, 85(2011), No.5, 911-921.
- [15] Kaldellis, J.K., Fragos, P., Ash deposition impact on the energy performance of photovoltaic generators, Journal of Cleaner Production, 19(2011), No.4, 311-317.
- [16] Al-hasan, Ahmad Y., Ghoneim, Adel A., A new correlation between photovoltaic panel's efficiency and amount of sand dust accumulated on their surface, Sustainable Energy 24 (2005), No.4, 187-197..
- [17] El-Shobokshy, M.S., Hussein, F.M., Degradation of photovoltaic cell performance due to dust deposition on to its surface. Renewable Energy 3(1993), No.6-7, 585-590.
- [18] Goossens, D., Van Kerschaever, E., Aeolian dust deposition on photovoltaic solar cells: the effects of wind velocity and airborne dust concentration on cell performance. Solar Energy 66(1999), No.4, 277-289.
- [19] The Yellow River news network, Global satellite data shows that Chinese air pollution is the most serious, 2010, http://www.sxgov.cn/news/news_content/2010-09/27/content_634100.htm
- [20] Global satellite data shows that Chinese air pollution is the most serious, 2010, <http://lanseshendajie.0421s.com/bbs/viewthread.php?tid=14854>
- [21] He L.D., Xinmin weekly, Urban air pollution investigation : how to do Guangzhou, 2009, <http://news.163.com/09/0415/22/56VNP7CD00011SM9.html>.
- [22] Yu G.H., Li L.L., and Li Z.G., et al, Taiyuan main air pollutant appraisal analysis and forecas, Environmental science and management, 35(2010), no.4,171-174.

Authors: Assistant prof. L.Q. Liu, college of electronic and Information engineering, Taiyuan University of Science & Technology, Waliu road 66, Wanbolin district, Taiyuan, China, E-mail: llqd2004@163.com; Assistant prof. Z.Q. Liu, college of Mechanical engineering, Taiyuan University of Science & Technology, Waliu road 66, Wanbolin district, Taiyuan, China, E-mail: wnewspaper2008@sohu.com; Prof. Z.Y. Sun, college of electronic and Information engineering, Taiyuan University of Science & Technology, Waliu road 66, Wanbolin district, Taiyuan, China, E-mail: sunzhiyi@263.net; Assistant prof. C.X. Liu, College of computer science & technology, Taiyuan University of Science & Technology, Waliu road 66, Wanbolin district, Taiyuan, China, E-mail: lcx456@163.com.