POWER QUALITY ANALYSIS OF PV SYSTEM OF SUMMER AND WINTER

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ABSTRACT

PV system has been rapidly developed in recent years, while it generates harmonics and there-phase unbalance for its grid-connected inverter, causing voltage fluctuations and flicker for its uncertain power output. Therefore, power quality is highlighted as an important parameter of the PV system. To study the actual power quality characteristics of PV system, a large-scale grid-connected BIPV power plant was investigated. This paper discussed power quality parameters defined by standards of PV system, and introduced the key structure of the BIPV system. Based on the field tests taken under different conditions in summer and winter, the paper explored the operating characteristics of the PV system on voltage harmonics, current harmonics, three-phase unbalance, voltage flicker, active and reactive power properties, etc. Results demonstrate the power quality characteristics and provide a reference for evaluation of similar PV systems.

INTRODUCTION

Among the renewable energy sources, Photovoltaic (PV) or known as solar energy shows a significant potential, and has been rapidly developed in recent years. The improvement of solar panel and power electronic converters has lead to high installation rates of grid-connected PV systems around global, which play an important role in reducing air pollutions, preserving underground resources and alleviating global energy crisis. [1]

In a grid-connected PV system, PV application produces DC voltage and can be converting to AC voltage by using inverter to connect to power grid. Therefore, grid-connected inverter is the key equipment providing the channel between PV application and public grid.[2] The inverter conversion process with power electronics is generally known as the switched-mode inversion, which make it a typical non-linear element, and could cause some power quality problems such as harmonics and there-phase unbalancing. The uncertain power output of PV systems could also cause voltage fluctuations and flicker. Therefore, power quality received a great attention as an important indicator of PV system. [3, 4]

POWER QUALITY STANDARDS OF GRID-CONNECTED PV SYSTEM

In order to regulate the connection of PV system to power grid and ensure operating safety, a series of technical requirements and standards have been developed around the world. Among which, the series of IEC and IEEE standards are widely recognized as guidance documents for the development of PV related standards in other countries. IEC 61727 and IEC STD 929 propose the requirement on utility interface of PV system, while IEEE 1547 is in response to distributed energy include PV.

Various standards have been established in several countries, such as Australian standard AS 4777 which gives requirement on grid connection of energy systems via inverters and American standard UL1741 for inverters, converters, controllers and interconnection system equipment for use with distributed energy resources. [5]

In China, standards of grid-connected PV system are mainly developed in recent years. GB/T 20046-2006 is the Chinese vision of IEC 61727-2004 with few changes. GB/T 19939 gives technical requirements for grid connection of PV system on the connection type, power quality, relay protection, automation, installation and etc. Two corporate standards were published by state grid corporation of China recently, specifying technical requirements and test procedures for grid-connected PV system. The following are several important indicators of power quality in these standards, and it is noteworthy that most of these indicators refer to China national standards of power quality of public grid.

Voltage deviation: referring to GB/T 12325. Voltage deviation should not exceed 7% of the rated voltage.
Frequency deviation: referring to GB/T 15945. Frequency deviation should not exceed 0.5Hz.
Harmonics: referring to GB/T 14549 and GB/T 24337. Current harmonics injecting into public grid are limited in accordance with the ratio of installation capacity of PV system and the short-circuit capacity at the PCC (Point of Common Coupling). In GB/T 19939, the specific value is provided: the current THD (Total Harmonic Distortion) should not exceed 5% of rated current.
Power factor: When the power output is greater than 50% of rated output, average power factor of PV system should not be less than 0.9 (lead or lag).
There-phase unbalance: referring to GB/T 15543. Voltage unbalance factor should not exceed 2%, and voltage unbalance factor caused by PV system should not exceed 1.3%.
Voltage fluctuation and flicker: referring to GB 12326. Voltage fluctuation caused by PV system should be

limited in accordance with the fluctuation frequency and voltage level. Voltage flicker caused by PV system should be limited in accordance with the ratio of installation capacity of PV system and the short-circuit capacity of the PCC. Flicker assessment should be ranked into there levels.

DC component: The DC current injecting into public grid from PV system should not exceed 0.5% of rated AC current.

STRUCTURE OF A LARGE-SCALE BIPV SYSTEM

The BIPV (Building Integrated PV) is the hotspot of the PV technology with much predominance. BIPV replaces conventional building materials with PV materials on the surface of the building, or attaches PV modules to the surface of the building, to reduce costs and save space.

The PV system concerned in this paper is located in Shanghai. It is one of the largest single-building BIPV projects in the world, with total investment of above 23 million dollar. Making full use of the building surface of 61,000 square meters, nearly 24,000 polycrystalline silicon PV modules was installed. Each module could generate power of 280W in maximum. The installation capacity of this project is close to 6.7MW, which could provide electrical energy for 12,000 families.

The PV modules are connected to four inverter rooms through 96 convergence boxes. Each room contains 3 inverters and 2 dry-type amorphous alloy transformers. The PV system is connected to public grid via 10kV voltage line. The schematic wiring diagram of the PV system is shown as Fig.1.

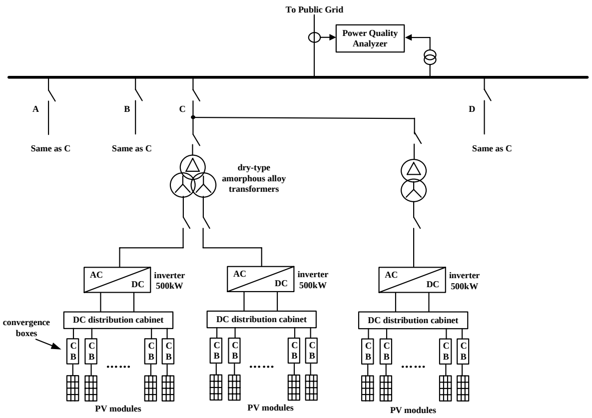

Fig.1 schematic wiring diagram of the PV system

There are 12 inverters in total, and their types are exactly the same type. Each inverter is constructed by IGBT elements in there-phase full-bridge circuit, with the rated output of 500kW, advanced MPPT (Maximum Power Point Tracking) technology, LVRT (Low Voltage Ride Through) technology and flexible active and reactive power adjustment function. Filtering devices are set both in DC circuits and in AC circuits. The schematic diagram of inverter is shown as Fig.2:

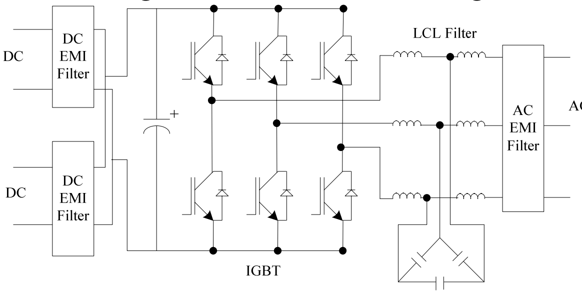

Fig.2 the structure of the inverter

To study the actual power quality characteristics of this PV system, some field tests are taken (shown in fig.1) under different light conditions in different seasons. The tests lasted a week in summer and winter respectively, and then the data under the best light condition was selected for analysis.

COMPARISON OF POWER QUALITY IN SUMMER AND WINTER

<u>light conditions and power output</u>

Winter

In January 2011, typical winter at Shanghai, the power quality filed test was implemented. A set of test data obtained in the day with best sunlight condition is analyzed. The temperature was about -1 to 4 degrees Celsius, and the effective irradiation time was around 7:00 am to 17:00 pm. Fig.3 shows the curves of light intensity, active power output and reactive power output in time interval form 6:00 am to 18:00 pm that day.

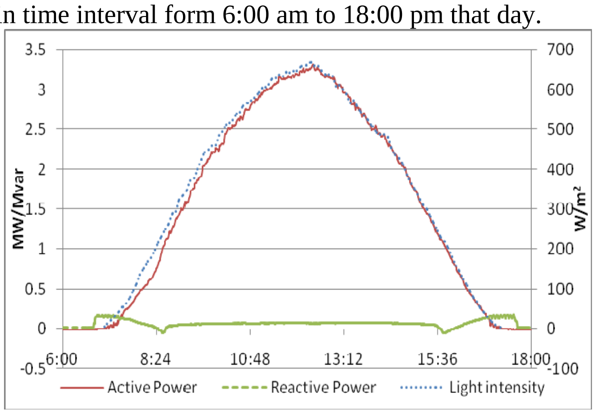

Fig.3 curves of light intensity, active power output and reactive power output in winter

The curves of light intensity and the active power output are well consistent. When the light intensity reaches strongest at 12:21 pm, the active power output of PV system has reached the maximum. The strongest light intensity is 669W/ m^2, and the maximum power output is 3.3MW. The power factor of the PV system basically stable around 1 when the power output is greater than 0.5MW.

. Summer

In July 2011, typical summer at Shanghai, the power quality filed test was implemented. A set of test data obtained in the day with best sunlight condition is analyzed. The temperature was about 28 to 36 degrees Celsius, and the effective irradiation time was around 5:00 am to 19:00 pm. Fig.4 shows the curves of light intensity, active power output and reactive power output in time interval form 4:00 am to 20:00 pm that day.

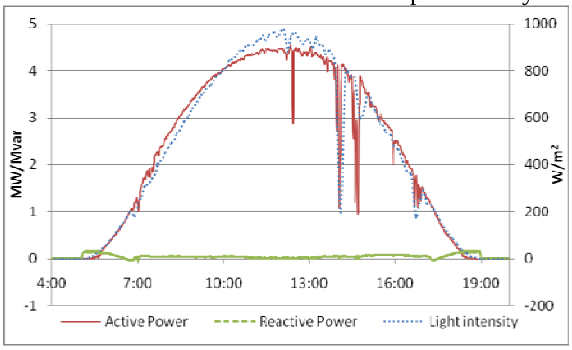

Fig.4 curves of light intensity, active power output and reactive power output in summer

The curves of light intensity and the active power output are well consistent. When the light intensity reaches strongest at 12:06 pm, the active power output of PV system has reached the maximum. The strongest light intensity is 974W/ m^2, and the maximum power output is 4.5MW. The power factor of the PV system basically stable around 1 when the power output is greater than 1MW.

The curves in Fig.4 show that when sunlight condition changes, the power output severely fluctuates, which could have an adverse effect on power grid dispatching. Compared the curves in Fig.3 and Fig.4, combined with the temperature data, it could be deduced that PV efficiency is decreasing.

Harmonics

According to test results, the three-phase voltage and current basically balance. Therefore, phase A is selected to analysis harmonics. Fig.5 shows the voltage harmonics spectrum during the stable irradiation time in summer and winter.

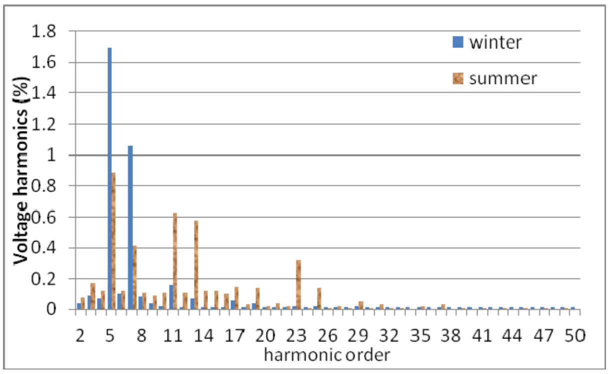

Fig.5 the voltage harmonics spectrum

5^{th}, 7^{th}, 11^{th}, 13^{th}, 17^{th}, 19^{th}, 23^{th} and 25^{th} harmonics are dominant in voltage harmonics. The statistic of these harmonics in winter and summer is shown in the table.1.

Table.1 Characteristic harmonics of voltage (%)

order	**THD**	**5**	**7**	**11**	**13**
winter	1.91	1.7	1.06	0.16	0.07
summer	1.23	0.89	0.41	0.63	0.58
limit	4	3.2	3.2	3.2	3.2
order	**17**	**19**	**23**	**25**	
winter	0.06	0.04	0.02	0.02	
summer	0.15	0.14	0.32	0.14	
limit	3.2	3.2	3.2	3.2	

Values of these characteristic harmonics are within the limits prescribed by GB/T 14549. Combined with the characteristics of current harmonics, it could be speculated that the background harmonic is the dominant component.

Fig.6 shows the harmonics spectrum of the current injected into public gird from PV system during the stable irradiation time in summer and winter.

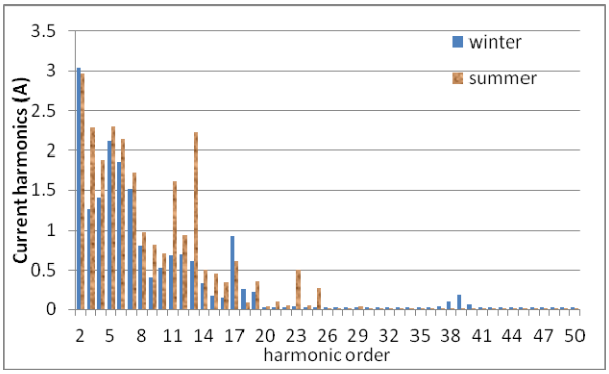

Fig.6 the current harmonics spectrum

There is no obvious characteristic order of current harmonics. Harmonics below 20^{th} are dominant, shown in the table.2. High-order harmonic is almost non-existent, and it could have been reduced by filters and transformers in the circuit of PV system.

Table.2 low-order harmonics of current (A)

order	2	3	4	5	6	7
winter	3.04	1.26	1.41	2.12	1.86	1.51
summer	2.97	2.29	1.89	2.3	2.14	1.73
limit	15.03	7.38	7.51	8.02	4.91	6.85
order	**8**	**9**	**10**	**11**	**12**	**13**
winter	0.8	0.41	0.53	0.68	0.69	0.6
summer	0.98	0.81	0.7	1.62	0.94	2.23
limit	3.7	3.93	2.95	5.06	2.49	4.44
order	**14**	**15**	**16**	**17**	**18**	**19**
winter	0.33	0.17	0.15	0.92	0.26	0.22
summer	0.51	0.46	0.35	0.6	0.09	0.36
limit	2.14	2.37	1.85	3.47	1.62	3.12

Values of these harmonics are similar in winter and summer, and they are also within the limits prescribed by GB/T 14549.

Three-phase unbalance

Table.3 shows the respectively maximum value of negative sequence unbalance factor of voltage and negative sequence current in winter and summer.

Table.3 Statistic of three-phase unbalance

	Negative sequence Unbalance factor of Voltage	Negative sequence current
Winter	0.16%	0.91A
Summer	0.29%	1.70A
Limit	2.00%	75A

According to the statistic, unbalance factors of both voltage and current are within the limit prescribed by GB/T 15543, which shows that the three-phase voltage and current are basically balanced.

Voltage flicker

Fig.7 shows the curves of short-term flicker severity (P_{st}) in winter and summer respectively.

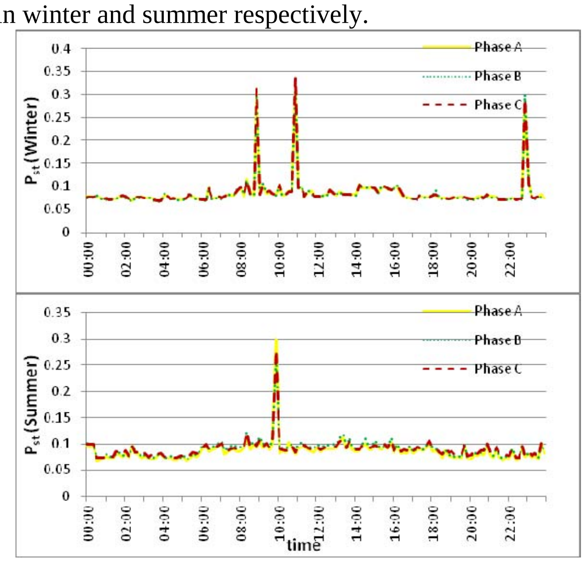

Fig.7 curves of short-term flicker severity

During the test, there are several abnormal fluctuations of P_{st} both in winter and in summer, which is not significantly associated with the operation of PV system.

GB/T 12326 prescribes the specific requirement on long term flicker severity (P_{lt}), but not on P_{st}, Table.4 shows the respectively maximum value of P_{lt} and P_{st} in winter and summer.

Table.4 Statistic of P_{lt} and P_{st}

	long-time flicker	short-time flicker
Winter	0.156	0.337
Summer	0.146	0.299
Limit	1	-

Values of P_{lt} are similar in winter and summer, and they are also within the limit prescribed by GB/T 12326.

CONCLUTIONS

Based on the field power quality test of a large-scale BIPV system under different light conditions in different seasons, the article presents the power quality characteristics of this PV system. Indictors such as power output, harmonics, three-phase unbalance and voltage flicker are analyzed, and the statistic shows that the power quality indictors of this PV system did not exceed the limit defined by China national standards both in winter and in summer. The result indicates that this PV system shows little impact on power grid in aspect of power quality.

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