Power Quality Survey of Photovoltaic GenerationIntegrated Grid

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***Abstract*—This paper analyzes impacts of grid-connected photovoltaic power plant on the harmonic current in the power quality aspect of distribution network, Summaries the requirement of harmonic current injecting in grid caused by photovoltaic power plant which connected in user side. Based on the DIgSILENT PowerFactory simulation platform, this paper simulates harmonic current injecting into grid in one case of grid-connected photovoltaic generation and then analyzes it by build models of photovoltaic generation and power grid belonged the user. The result illustrated that the harmonic current caused by user side grid connected photovoltaic generation injecting into grid satisfies standards requirements, the photovoltaic generation system should have 400kvar reactive power regulation capability.**

***Index Terms*—Distributed generation, photovoltaic generation, power quality.**

I. Introduction

Recently, the research and application of photovoltaic generation technology which based on utilizing solar energy is growing rapidly. According the Medium and Long Term Renewable Energy Planning of China in 2007, the installed photovoltaic generation capacity will reach 18GW in 2020. However, with the rapidly developing of photovoltaic industry, the aim has been expanded ten times to 200GW by National Energy Administration of China.

On one hand, large amount of photovoltaic generation integrated with grid promotes the utilize of solar resources, on the other hand, the photovoltaic generation brings new challenges on the planning and designing, power quality, operation, protection etc. Especially, after photovoltaic generation connected to distribution network, the structure of topology and the direction of flow of grid are changed, and simultaneously the power quality of users is influenced by photovoltaic power output characteristics.The impact of integration of photovoltaic generation with grid on power quality is mainly reflected in two aspects which are voltage fluctuation and harmonics.

The output power of PV generation is affected greatly by light illumination with the characteristics of volatility, intermittent and periodicity which would cause the voltage fluctuation and voltage flickering of grid. With the proportion of PV generation in power resources becoming larger, the influence of the characteristics of volatility, intermittent and periodicity on peak shaving of grid will be greater which would cause the frequency of grid variation. And, there are voltage pulses, surge, voltage sag and momentary interruption dynamic power quality problems caused by PV generation[1]. There are many hazards of harmonic in power system, mainly are[2], [3]: easily causing protection fault, resonance, over-voltage, over-current and increasing loss of transmission lines and motors.The purpose of adjusting reactive power and voltage is to guarantee the voltage level and power quality on the point of common coupling (PCC) of photovoltaic (PV) plant. The capability of voltage adjustment and reactive power providing is vary with the development of technology. Some PV plants use the capability of inverter providing reactive power and inverter voltage adjustment capability. In some PV plants, the reactive power would be regulated by change the amount of reactive power compensation equipment connecting to grid and the transformer voltage ratio. In PV plant, it is better that utilizing the capability of adjusting reactive power by PV inverter.

This paper mainly analyzes the impact of grid-connected photovoltaic power generation on power quality of harmonic current and reactive-power/voltage in distribution network, gives summary of the requirement of power quality caused by photovoltaic power plant which connected in the user side. The analysis result of simulating reactive power/voltage and harmonic current injecting into grid in one case of grid-connected photovoltaic generation bases on DIgSILENT/PowerFactory simulation platform shows that the harmonic current caused by user side grid connected photovoltaic generation injecting into grid satisfies standards requirements and the photovoltaic generation system should have 400kvar reactive power regulation capability

II. Power Quality Requirement of PV Generation

To assure power quality of power system, a series of standards rule the requirement of power quality of grid and power generation including PV generation. In that, there are 6 national standard refer to power quality in China which are GB 14549 Quality of electric energy supply Harmonics in public supply network, GB 15945 Quality of electric energy supply Permissible deviation of frequency for power system, GB 12325 Power quality- Admissible deviation of supply voltage,GB 12326 Quality of electric energy supply Admissible voltage fluctuation and flicker,GB 18481 Power-Temporary and transient overvoltage,GB 15543 Quality of electric energy supply Admissible three-phase voltage unbalance factor.

These standards are very important reference for drafting standard of integration of PV generation. In the aspect of power quality, PV generation is mainly under the rule of “Technical Requirement of Photovoltaic Station Connected to Power Grid (TRPSCPG)”. The standard specifies the requirement index of harmonics, voltage deviation, voltage fluctuation and voltage flickering, voltage unbalance, direct current component. The permissible value of harmonic current injected by PV generation is assigned by the ratio of installed PV generation capacity and capacity of device on the common couple point.

III. Photovoltaic Generation System Modeling

The detail model of PV generation system is build by DIgSILENT PowerFactory simulation platform. Current injected from PV generation to grid could be transfer into fundamental component and harmonic component. The frequency of fundamental current is same as the frequency of grid, and its amplitude is relevant to output power of PV generation. The harmonic current of PV generation is high frequency current, and its amplitude depending on characteristics of PV generation hardware and harmonic impedance of grid. The fundamental current model and harmonic current model are built separately by different modules on the DIgSILENT PowerFactory platform.

PV generation fundamental current model. As shown in Fig. 1, typical PV generation system consists of PV arrays, PV inverter, controller, monitor and protection system etc. In some case, there is energy storage system in PV generation. Inverter is the core of the whole grid-connected PV generation system. Maximum power point tracking(MPPT) controller is a part of inverter, so the fundamental power model is divided into PV array and inverter.

Fig. 1. PV generation system structure

The DC side of PV generation is replaced by a controllable DC source with IV characteristics of PV panel of simplified engineering mode [4].

On AC side of PV generation, the PV inverter control model is build by inverter module in Power Factory. Generally, without considering the factor of inverter saturation, the modulation ration P_{md} and P_{mq} of ideal inverter is obtained by the inner current control loop as shown in Figure. 2. Parameter Id_ref and Iq_ref are determined by control targets.

Actually, output power of PV generation is variable with the outer condition changing. When illumination intensity and temperature changing, the Maximum Power Point Tracking (MPPT) controller would adjust the operating voltage to the optimum point under the certain condition. Therefore, in PV inverter model with MPPT module, Id_ref and Iq_ref is calculated from control targets such as DC side voltage Udc and power factor θref .

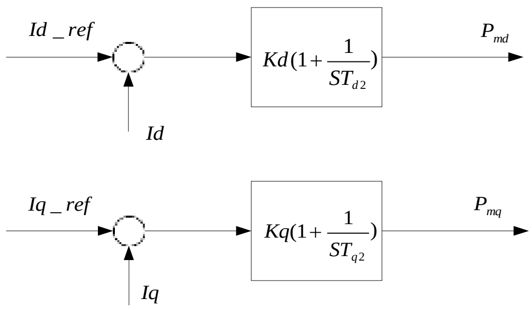
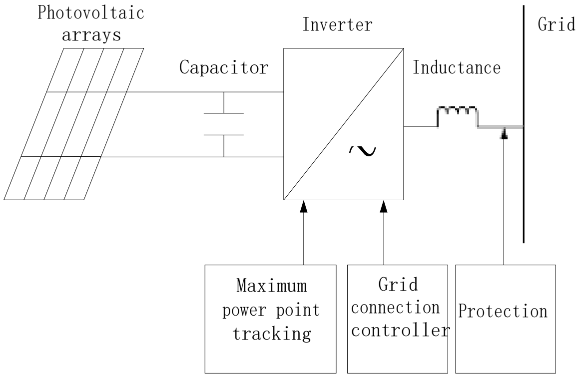


Fig. 2. Current feedback control loop

PV generation harmonic current model. Because of little affection of output power of PV generation on harmonic current, separate model of fundamental current and harmonic current could represent the real working condition. The harmonic current of PV generation is relevant to :Topology of PV inverter [5];Switching frequency and control algorithm of PV inverter [6];Output filter of PV generation [7];Harmonic impedance of grid [8];

In DIgSILENT PowerFactory, the PV generation harmonic current model is built by inputting harmonic current of PV inverter into Harmonic module of Static Generator model. The data of harmonic current is from the testing of inverter according standard GB 14549.

In harmonic current testing condition requirement, before and after PV generation injecting current into grid



the harmonic voltage of grid should satisfies a certain value, the influence of harmonic impedance variation of grid on PV generation output harmonic current is negligible. PV generation output harmonic current is larger in larger fundamental current condition. So, the state of harmonic current in the largest fundamental current condition is the worst state. Therefore, the model could be used to simulate the worst condition of PV generation connected to grid in user zone.

IV. CASE ANALYSIS

The case is analyzed according to TRPSCPG, which is a building integration PV system. The user has one 35kV substation which has one transformer (type: SFZ10-12500/35). The PV1 capacity is 3.25MWP whichconnected to local substation by 800m line. The active load of Load1 is 6482kW and reactive load is 2495kvar as shownin Figure 3.

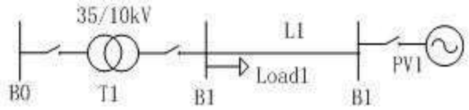


Fig. 3. The structure of Integration of PV generation into grid

Harmonic current analysis. The PV generation use one type of 500kVA PV inverter, the rated current is 1070A. The harmonic current data is shown in Table I.

According the "Technical Requirement of Photovoltaic Station Connected to Power Grid", considering the integrating solution of PV generation, the largest injecting harmonic current in PV generation operating is calculated. The result is shown in Table II.

TABLE I: HARMONIC CURRENT(HC) OF 500KVA INVERTER

Harmonic order	HC (%)	Harmonic order	HC (%)
2	0.553	14	0.024
3	0.739	15	0.026
4	0.051	16	0.030
5	0.574	17	0.350
6	0.038	18	0.130
7	0.017	19	0.079
8	0.030	20	0.046
9	0.018	21	0.028
10	0.013	22	0.018
11	0.055	23	0.053
12	0.011	24	0.008
13	0.131	25	0.034

The transformer in PV inverter is Dyn11 transformer. Delta winding contributes a passage for 3rd order harmonic current in which the 3rd harmonic flux could be neutralized. In Table.2, it is shown that under 25th order harmonic current permission value on 10kV bus in user's substation. By comparing the data, the injected harmonic current caused by PV generation is in the range of standard rules.

TALBE II: MAXIMUM HARMONIC CURRENT AND THE PERMISSION VALUE OF HARMONIC WHEN PV GENERATION OPERATING

Harmonic order	Harmonic current(A)		Harmonic current(%)	Harmonic current(A)	
	Max.	Permission value		Max.	Permission value
2	1.7972	6.76	14	0.78	0.962
3	-	5.2	15	-	0.286
4	0.1657	3.38	16	0.098	0.832
5	1.865	5.2	17	1.138	1.56
6	-	2.21	18	-	0.728
7	0.055	3.9	19	0.256	1.404
8	0.098	1.664	20	0.150	0.676
9	-	1.768	21	-	0.754
10	0.0423	1.326	22	0.059	0.598
11	0.1783	2.418	23	0.172	1.17
12	-	1.118	24	-	0.546
13	0.4258	2.054	25	0.110	1.066

Reactive power/voltage analysis. The principle of evaluating and calculating the reactive configuration of PV generation connected to internal grid in user-side are:

1) With PV generation connecting, the voltage level of grid should stable in normal range.

2) With PV generation connecting, reactive power configuration should assure that the reactive power exchange between PV generation and grid on the PCC is zero.

The reactive power exchange/voltage at the PCC of the PV generation system are simulated according GB/T 12325-2008 Power quality- Admissible deviation of supply voltage specifying about admissible deviation of supply voltage at 35kV level. The simulation is done under each condition that Bus B0(35kV) is in different voltage value and considering different PV generation power output.

When PV generation is in full output condition, the calculating result of reactive power exchange and voltage at PCC accounting 1.5Mvar reactive power compensation devices is shown in Table III.

TABLE III: REACTIVE POWER/VOLTAGE IN PV FULL GENERATING STATE IN DIFFERENT VB0

VB0(p.u.)	1.05	1.02	1.00	0.97	0.95
VB2(p.u.)	1.03	1.00	0.98	0.95	0.93
VB3(p.u.)	1.04	1.01	0.99	0.95	0.93
QB3(Mvar)	-0.34	-0.36	-0.38	-0.40	-0.42

NOTE:"-"MEANS ABSORBING ,"+" MEANS OUTPUTING

As Table III shown, when PV generation is in full output condition and bus B0 is in different voltage, the voltage of user internal grid is in normal range except that after the voltage at B0 dipping to 0.95 p.u.., the voltage of user internal grid dipping out the limiting value that 0.95 p.u.

TABLE IV: REACTIVE POWER/VOLTAGE IN WITHOUT PV GENERATING IN DIFFERENT VB0

VB0(p.u.)	1.05	1.02	1.00	0.97	0.95
VB2(p.u.)	1.02	1.00	0.98	0.95	0.93
VB3(p.u.)	1.03	1.00	0.98	0.95	0.93
QB3(p.u.)	-0.01	-0.01	-0.01	-0.01	-0.01

As Table IV shown, the voltage of user internal grid is out of the limiting value when bus VB0 dipping to 0.95 p.u.

V. CONCLUSION

This paper analyzes impact of grid-connected photovoltaic power generation on power quality in distribution network. Summaries the requirement of power quality problems caused by photovoltaic power plant which connected in the user side. Based on the DIGSILENT/PowerFactory simulation platform, this paper simulates harmonic current injecting into grid and reactive power/voltage in one case of grid-connected photovoltaic generation and then analyzes it by developing models of photovoltaic generation and power grid belonged to the user. The result illustrated that

1) the harmonic current caused by user side grid connected photovoltaic generation injecting into grid satisfies standards requirements;
2) the photovoltaic generation system should have 400kvar reactive power regulation capability.

It is necessary that evaluating the impact of integration of PV generation on voltage fluctuation, voltage flickering and harmonic voltage etc. as they are important aspects in power quality indexes.

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