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Analysis of voltage and frequency of the grid-connected photovoltaic system

Muratov Kh.M.,Turaev A.I

DSc, Professor, Scientific and Technical Center of the Academy of Sciences of the Republic of Uzbekistan, 100074, Tashkent, Uzbekistan
Senior scientific researcher, Scientific and Technical Center of the Academy of Sciences of the Republic of Uzbekistan, 100074, Tashkent, Uzbekistan

ABSTRACT: In this work the changes in voltage and frequency during the parallel operation of a 9 kW photovoltaic system with the local electrical network connected with central energy system are investigated. It is shown that the average voltage deviation relative to the nominal one is 1.5%, and the frequency fluctuation were less than 0.1 Hz.

KEYWORDS: Photovoltaic system, voltage variation, variation frequency, power quality**.**

1. INTRODUCTION

Currently, the interest of developed countries in the development and use of renewable energy sources (RES) is due to limited land resources and environmental problems [1,2,3,10]. It is known that in recent years, with the commissioning of new production facilities throughout the Republic, the demand for electricity in the regions is growing, as a result, the load on the power system increases, which leads to instability of the electric network (voltage surges / drops, frequency distortions). One of the solutions to this problem is to connect renewable energy facilities to the local electrical network in order to increase the voltage at the time of peak loads [4]. It should be noted that solar energy occupies a leading place among renewable energy sources in the world in terms of its technological availability.

In the Republic, the impact of low-power RES-based generating capacities connected to the grid (on-grid) on the parameters of the local low-voltage network has not been sufficiently studied. In this work, the influence of an on-grid SPP with a capacity of 9 kW on the parameters (voltage, frequency) of a local low-voltage (0.4 kV) electrical network connected to a centralized power system is considered.

II. LITERATURE SURVEY

Electricity generated by high-capacity power station is supplied to users several hundred kilometersaway by power transmission lines. In power lines, the grid voltage is monitored and controlled at substations. In the power grid the reactive power consumers and consumers with low active power factor causes voltage drop. Reactive power compensation technologies are used in order to improve the quality of electricity in the distribution networks. Below, some classic compensation methods are briefly described. We are mainly concerned with the management of reactive power transmitted through grid connected PV inverters[4,6,9,10].

Synchronous generators method, by changing the excitation current, we achieve controlling reactive power (Turitsyn et al., 2011; Kundur, 1994). This method gives an effective possibility to control and stabilize the high-voltage power lines. At the same time, the reactive power generated causes large losses in the high voltage power line (Cherfa et al., 2014; Braun, 2007).

Reactive power compensation devices are commonly operated and installed in the distribution power networks from regional utility companies. One of the reactive power compensators is called capacitor bank. These devices consist of several powerful condensers which we can use like as resource of reactive power.

The inverter belongs to an emerging class of reactive power control that is not widely deployed, but there are several reasons to develop the inverter solution as a reactive power controller:

-The proximity of the reactive generation reduces the thermal losses in the line.

-The distributed nature of PV generators allows flexible and optimal reactive power control by inverters.

The grid-connected PV inverter is a limited resource of reactive power. PV inverters capacity depends(to generate reactive power) on its full power value and the active power injected from the PVmodules. Therefore, the inverter can generate maximum reactive power if the generated active power equals zero (no irradiation). In the other extreme, active power equal apparent power, the minimum of reactive power is produced[1,5,8,11].

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III. MATERIAL AND METHODS

It is known that solar photovoltaic modules directly convert solar energy into direct electric current. The SPP is connected to the grid by means of a network (on-grid) inverter, which converts direct current into alternating current. In this case, the output parameters of the inverter must correspond to the parameters of the electrical network, i.e. strictly according to the standards [4,5,6,7,8]. At any overestimated or underestimated values of one or another network parameter, the inverter is automatically disconnected from the network. The SPP under consideration is connected to the network through an inverter of the PV-C310ML type from HEXPOWER (Korea)). The parameters of the above inverter are shown in table 1.

Table 1: Technical Parameters of HEX POWER PV-C310ML Inverter

Dir. control out.	Grid-connected(non-isolated)	Coef. power	More than 0.99 (at rated load)
Dir. control input.	MPPT (Maximum Power Tracking)	Max. efficiency	97.37%
V_{DC} МАКС	DC 900 V	European efficiency	96.80%
MPP range	DC 450~720 V	Frequency	60/50Hz(+0.5Hz/-0.7Hz)
Range voltage	DC 400 ~ 900 V	Monitor	Graphic LCD and Keys LCD (HMI)
I_{DC} МАКС	25A	THD Коэф. нелинейныхиск.	<5% Total, <3% Individual
Capacity	10.5 kW	Nom voltage	380 V AC

The parameters of the SPP and the electrical network were determined using the PROVA210A (Taiwan, measurement error 1%), Solsensor200 (USA, measurement error 0.5%) and Fluke 190-104 / S (USA, measurement error 1.5%).

IV. SIMULATION&RESULTS

For the experiments on determination, favorable days for the station were chosen, i.e. when the SPP generates the highest power (table 2). At the same time, the output parameters of the SPP connected to the network were taken into account, depending on weather conditions.

Table 2: Output parameters of PV system during the experiment

Time(hour)	Radiation (W / m2)	Temp. Arr. Art. PV module (° C)	Temp. Over. PV module (° C)	P_{MAK} (W)	I_{shc} (A)	V_{MAK} (V)	V_{oc} (V)	FF(%)	PR(%)	η(%)
11:30	1000	59,7	57,6	7560	17,8	462,1	599,3	0,7	0,84	14,38
12:00	1000	57,4	57,3	7554	17,7	463	600,5	0,77	0,84	14,37

Table 2 shows the measurement results: fill factor FF (%) - the ratio of the maximum attainable power to the product of open circuit voltage and short circuit current; PR (%) - the productivity factor is one of the main parameters describing the operation of the SPPP and is associated with the amount of energy generation, which is determined by the ratio of the actual generated power under natural conditions to the maximum calculated value of the generated power [9]. PR is

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indicated as a percentage and describes the relationship between the real and theoretical possible energy output from the SPP. In addition, PR depends on both the quality of the system components and weather conditions, and allows you to control the efficiency of the system; Efficiency η (%) SPP.

One of the main parameters of the electrical network is the voltage deviation ΔU, which should not exceed a certain value, and the permissible deviations are set out in the normative documentation [5]. The voltage deviation is described by the following formula [6].

$$\Delta U = \frac{U_{\text{H}} - U_{\text{C}}}{U_{\text{H}}} * 100\%. \qquad (1)$$

where U_H (V) is the rated voltage of the power supply network, U_C (V) is the voltage of the power supply network obtained during the experiment.
The measurement results showed that after connecting the SPP to the network, there were small voltage deviations in the electrical network (Table 3). The measured values of the voltage of the electric network were: 384V, 385V and 380 V. According to the quality indicators of electricity, this is not a very dangerous situation. For 0.4 kV power lines, up to 5% and up to 10% are allowed in short-term hazardous conditions [5,11]. The average voltage deviation in the local network did not exceed 1.5%, which meets the requirements of GOST [5].

Table 3: Grid voltage parameters depending to the nominal voltage

Phase	U_{C}(V)	U_{H}(V)	ΔU%	GOST(for0.4 kV)
A	384	380	1.053	$\Delta U_{\text{мин}} \leq 5\%$ $\Delta U_{\text{мах}} \leq 10\%$
B	385		1.316	
C	380		0	

When connecting the SPPS to the network, the voltage deviation relative to the network is determined by the following formula:

$$\Delta U_{И} = \frac{U_{И} - U_{C}}{U_{C}} * 100\% \qquad (2)$$

where, $\Delta U_{И}$ is the voltage deviation when the SPP is connected to the electrical network, U_C is the voltage of the electrical network (table 4) [6].
When measuring the output parameters of the SPP inverter at the point of connection to the network, a slight voltage deviation was observed. The measured phase voltages were 385V, 386V and 383V, respectively. The deviation of the output voltage relative to the mains voltage does not exceed 1%, which is allowed within the experimental error. When calculated relative to the nominal, the average voltage deviation was 1.5%.

Table 4: Grid voltage parameters depending to the nominal voltage, when PV system connected to the grid

Phase	$U_{И}$(V)	U_{C}(V)	U_{H}(V)	ΔU(%)	$\Delta U_{И}$(%)	GOST(for0.4 kV)
A	385	384	380	1.316	0.26	$\Delta U_{\text{мин}} \leq 5\%$ $\Delta U_{\text{мах}} \leq 10\%$
B	386	385		1.579	0.26	
C	383	380		0.789	0.789	

On the territory of the CIS and in many other countries of the world, the value of the nominal frequency of sinusoidal alternating current in the power grid is 50 Hz [5; 8]. According to the requirements of [10], in terms of the quality of electrical energy, permissible frequency changes are one of the main parameters of the network.
The change in frequency is calculated using the following formula [5]

$$\Delta f = f_{HOM} - f_C \text{ (Hz)} \qquad (3)$$

here Δf is the frequency change, f_{HOM} is the specified nominal frequency, f_C is the frequency of the electrical network.

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In this order, the change in frequency relative to the nominal frequency is determined when the SPP is connected to the network:

$$\Delta f_{ИН} = f_{НОМ} – f_{И} \qquad (4)$$

The change in the frequency of the SPP relative to the electrical network is determined as follows:

$$\Delta f_{ИС} = f_{С} - f_{И} \qquad (5)$$

here $f_{ис}$ is the value of the SPP frequency when connected to the network.

In the electrical network itself, you can see small frequency changes (Fig. 3). At the same time, the results obtained, after connecting the SPP to the electrical network, correspond to the requirements allowed for changing the frequency. From table 5, you can see that the frequency deviation relative to the electrical network does not even reach 0.1 Hz, which lies in the permissible frequency range.

Table 5: The value of frequency variation

Phase	$f_{С}$ (Hz)	$f_{И}$ (Hz)	$f_{НОМ}$ (Hz)	Δf (Hz)	$\Delta f_{ИН}$ (Hz)	$\Delta f_{ИС}$ (Hz)	GOST (Hz)
A	49.99	50.07	50	0.01	0.07	0.08	$f_{мин} \leq \pm 0.2$ $f_{max} \leq \pm 0{,}4$
B	49.97	50.06		0.03	0.06	0.09	
C	49.98	50		0.02	0	0.02	

The analysis of the results shows that the 9 kW SPP does not have a significant effect on the voltage and frequency fluctuations of the 0.4 kV local electrical network connected to the centralized power system. With a significant increase in the power of SPP in the local network, changes in the voltage and frequency of the local electrical network can also be noticeable and require further detailed experimental studies.

V. CONCLUSION

Thus, it is shown that when the SPP inverter (9 kW) operates in parallel with a 0.4 kV local electric network (at a load of less than 30%), significant voltage and frequency deviations are not observed, and there were no higher harmonics. Taking into account the errors of measuring devices, the SPP with an installed power of 9 kW, practically did not affect the parameters of the local electrical network connected to the centralized power system. It is shown that the average voltage deviation relative to the nominal was 1.5%, and the frequency deviation was less than 0.1 Hz.

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AUTHOR'S BIOGRAPHY

MuratovKhakimMakhmudovich

DSc, Professor MuratovKh. is currently the Director of the Scientific and Technical Center of the Academy of Sciences of the Republic of Uzbekistan. He received his doctorate in electrical drive engineering. In addition to his academic career, Kh. Muratov is engaged in teaching activities as well.

TuraevAkramjonIkromjonovich

TuraevA. is currently a senior scientific researcher at the Scientific and Technical Center of the Academy of Sciences of the Republic of Uzbekistan. He received his master's degree in electrical engineering at the Tashkent State Technical University. In addition to his academic career, A. Turaev was engaged in teaching activities.