Performance analysis and modelling of grid-connected small photovoltaic system

Atanas CHERVENKOV*, Atanas YANEV* and Todorka CHERVENKOVA**

*Technical University of Sofia, Faculty of Automatics, Department of Theoretical Electrical Engineering, 1000 Sofia, Bulgaria, E-mail: acher@tu-sofia.bg

**Technical University of Sofia, Faculty of Engineering and Pedagogy, Department of Electrical Engineering, Automatics and Information Technology, 8800 Sliven, E-mail: tchervenkova@tu-sofia.bg

***Abstract*—A grid-connected 30 kW small PV system, located in Southeast Bulgaria has been studied. Performance analysis of the PV system is done. The PV system is balanced according reactive power. The total harmonic distortion THD of the object is very low and satisfies the requirements of the standards. A model of PV system is created in MATLAB. Simulations of the operation in different modes have been carried out. The electromagnetic compatibility of analyzed small PV power system is satisfied.**

Keywords—electromagnetic compatibility, modelling, performance, photovoltaic system.

I. INTRODUCTION

The small PV power system, located in Southeast Bulgaria is investigated. The plant is located at latitude 42°41'25.0"N, longitude 26°22'09.0"E and 243 m altitude. The temperature varies between -2°C and 32°C. The problems related to the interaction of the PV system with the network are the quality of the supply power.

IEEE Standard 1547-2003 gives interconnection requirements for renewable resources. [1]. IEEE Standard 519-2014 gives limits of harmonics permitted in the network [2].

An analysis about voltage, current, active power, power factor and Voltage THD (Current THD) is done.

II. POWER STATION DETAILS

The 30 KW PV plant use Polycrystalline silicon PV modules TRITEC TRI-MAX EU 250Wp. The modules are placed on a support rail with spacing to ensure free flow on air under the modules. A string by combination of series connecting modules (6 strings of 20 modules) is formed. PV system uses one HUAWEI SUN2000-33KTL - 30 KW. The inverter outputs at 400 V, 50 Hz.

An electronic four-vector meter logs the energy. It transfers data to server files continuously. Data logger system collect information about operating parameters: voltage, current, power, solar radiation and temperature. This information from multiple sensors through RS 485 bus is collecting. PV system use SCADA server like other PV systems. The server receives this information and updates the data on graphical screens [3]

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Data is archived with information for each day. The system collects data annually and for each month also.

The power of the PV system is influenced by light illumination and the temperature of the solar cells. This would cause voltage fluctuations and voltage flickering. Then the voltage pulse of the transmission lines will be noticeable and difficult for elimination. The output power of the inverter will be of poor quality in low light illumination. Under these conditions, the output power of the photovoltaic system will be small and the inverter operation will be unstable. When the power inverter is relatively low appears nonlinearity and therefore there will be more harmonics in the output voltage.

The electricity generation prediction from the PV system using RETScreen Expert software tool [4] is calculated. Some results are presented in Fig.1.

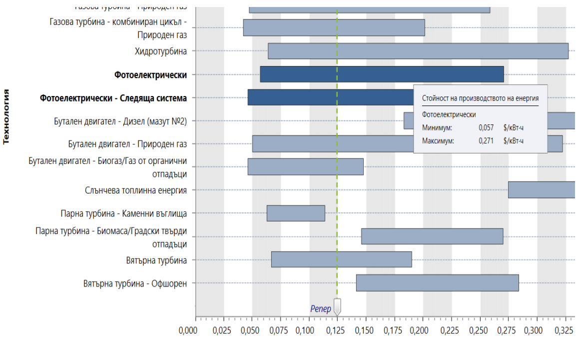

Fig. 1. Snapshot from electricity generation prediction of PV system

III. PERFORMANCE ANALYSIS

The performance analysis with apparatus Metrel MI 2392F was conducted. Metrel MI 2392F is handheld multifunction instruments for power quality analysis and energy efficiency measurements [5, 6]. For gathering the necessary information, the device is connected to the inverter via L1/2/3 Clamp: Smart(3x300A), range 100%; U range: 240-1000V L-N; Connection: 4W. Several measurements are made over a certain time interval, each of 200ms duration and a density of 1024 points. Some results of the operation of photovoltaic power system in normal mode in Fig. 2 are given. In Table 2 a summary of the measurements is shown.

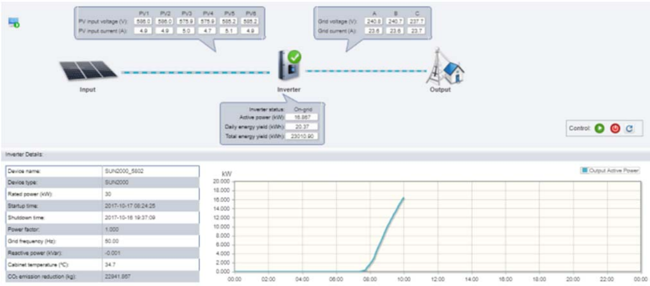

Fig. 2. Snapshot from PV power system monitoring system

TABLE I. SUMMARY OF THE MEASUREMENTS

Symbol	Name	L1	L2	L3	Total
U	Voltage, V	239.6	238.8	239.2	---
I	Current, A	39.40	39.30	39.29	---
THD U	Voltage THD, V	3.27	2.77	3.22	---
THD U	Voltage THD, %	1.36	1.16	1.35	---
THD I	Current THD, A	1.08	0.96	1.13	---
THD I	Current THD, %	2.75	2.44	2.87	---
u-	Negative Sequence Voltage Ratio, %	---	---	---	100
u0	Zero Sequence Voltage Ratio, %	---	---	---	100
i-	Negative Sequence Current Ratio, %	---	---	---	100
i0	Zero Sequence Current Ratio, %	---	---	---	97.49
CFu	Voltage Crest Factor	1.41	1.42	1.41	---
CFi	Current Crest Factor	1.49	1.49	1.46	---
Umin	Voltage Min Peak, V	-335.7	-336.6	-337.6	---
Umax	Voltage Max Peak, V	337.2	338.1	338.4	---
Imin	Current Min Peak, A	-60.73	-60.57	-59.32	---
Imax	Current Max Peak, A	63.46	63.50	62.9	---
P	Active Power, kW	9.42	9.36	9.38	28.16
N	Reactive Power, kVAr	0.44	0.72	0.57	1.73
PF	Power Factor	1.00 ind	1.00 ind	1.00 ind	1.00 ind
DPF	Displacement Factor	1.00 ind	1.00 ind	1.00 ind	1.00 ind
S	Apparent Power, %	9.44	9.39	9.40	28.23

The picture of the measured voltages in the three phases and the current in the middle phase in Fig.3 is shown.

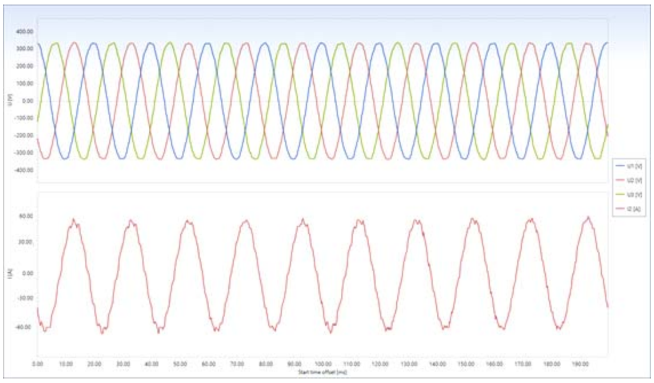

Fig. 3. Waveforms of voltages and current in normal mode

The shape of the voltage and current are close to the sinusoidal curve.

The results of Voltage THD and current THD in Fig.4 is given.

Fig. 4. THD of the voltages and one current

A closer view for the total harmonic distortion for the voltages and their values in Fig.5 are shown.

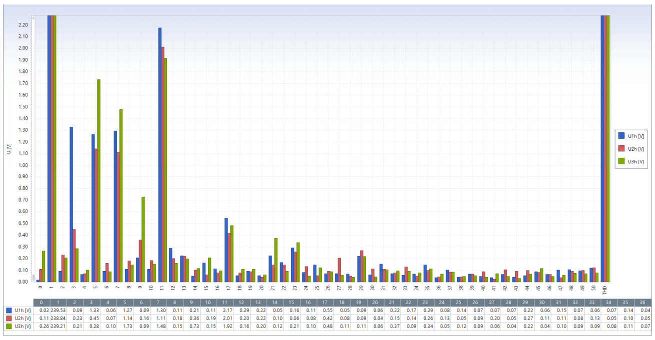

Fig. 5. A closer view for THD

The power system is balanced according reactive power. The main purpose of the quality analysis is the electromagnetic interference generated by the photovoltaic plant and in particular - THD. The total harmonic distortion is minimal according to IEEE 519 [2].

IV. PV System Model

A model of power system in MATLAB is created. The photovoltaic system is modeled using MATLAB software tool [7] to analyze their work. A control technique is using to accomplish maximum generating power from the solar plant. The results of the simulation prove the stability and reliable operation of the investigated system.

The investigated PV system using SIMULINK is simulated. A 30-kW PV system is considered. Fig. 6 shows the PV system simulation scheme.

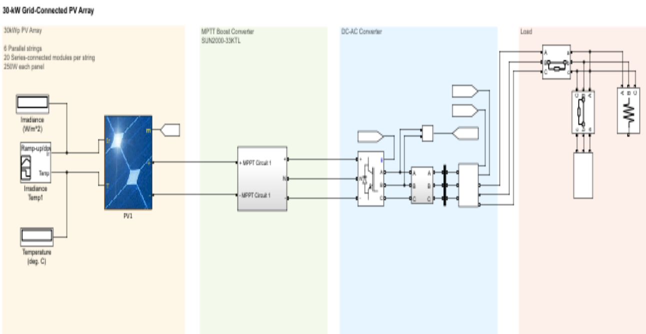

Fig. 6. Block diagram of the simulated PV system

The Simulink model consists of 30 KW PV plant, SUN2000 33KTL 30kW 3phase Solar Inverter, 3phase LV transmission line and 3phase load.

The 30 kW PV array consists 6 parallel strings of 20 series-connected PV modules. 250 Wats Poly crystalline silicon PV modules are modelling.

The power of the photovoltaic system depends mainly from the solar radiation and the cell temperature. The current–voltage relationship at a fixed cell temperature and solar radiation for is used [8]. The irradiance at 1000 W/m2 and temperature of 30 degrees Celsius is modeling.

Electronic converters used in photovoltaic power systems are the major source of harmonics. PV inverters use semiconductor devices with minimal losses [9] by the transformation of the DC photovoltaic power to the output AC power. Pulse Width Modulation switching is the most commonly used way for the generation of AC voltage. PWM allowing for flexible control of the output voltage magnitude and frequency. But all PWM techniques generate harmonics and noise originating in the high dv/dt and di/dt semiconductor switching transients [10]. That is why it is imperative to provide ways to eliminate harmonics An LCL filter is often used to interconnect an inverter to the utility grid in order to filter the harmonics produced by the inverter [11].

The inverter model contains DC-DC converter, 3 phase DC-AC inverter and LC filter.

V. Simulation Results and Disscusion

Simulations of the power system operation in normal mode, idle mode and short circuit mode is carried out.

A. *Results in normal mode operations*

In normal mode, the photovoltaic system supplies the electrical loads located in the vicinity around, through the low voltage distribution network.

The power system is balanced according active and reactive power in normal mode. Generated power has an optimal value for the economic efficiency of PV plans.

The simulation result of the active power P of the PV system in normal mode in Fig. 7 is shown.

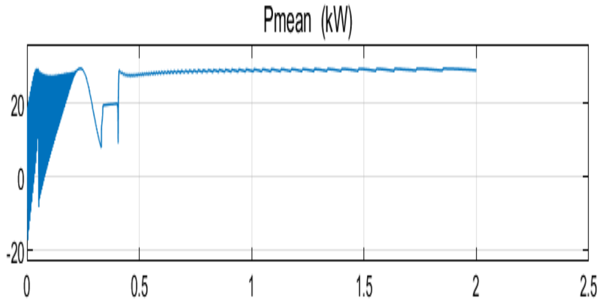

Fig. 7. Simulation result of the active power P

Instability in the initial 0.5 seconds is depending of the transition process in the modification of the duty cycle D. Stable process is obtained with a larger pulse width PW and D> 0.6.

The simulation result of the voltages of the PV system in Fig. 8 is shown.

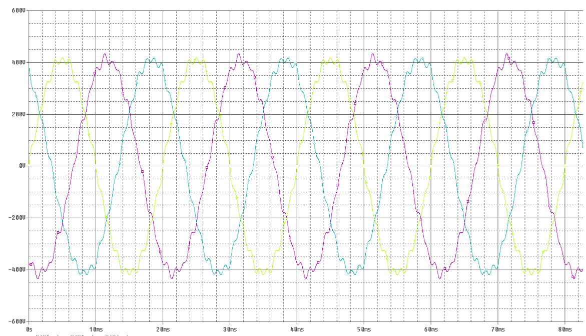

Fig.8. Simulation result of the voltages in normal mode of PV system

The voltage THD is 4.1 % and satisfies standard IEEE 519 [2].

B. *Results in extreme mode operations*

As extreme modes two cases - idle and short-circuit at the output of the photovoltaic system are considered.

Initially, idle mode is simulated. It is case of interruption in one phase of the low voltage distribution network.

The simulation result of the voltages in idle mode of the PV system in Fig. 9 is shown. The shape of voltages is close to the sinusoid and THD is low, respectively.

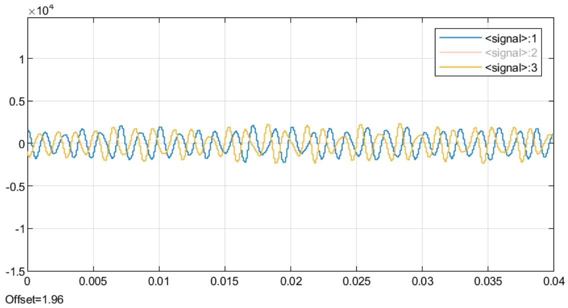

Fig.9. Simulation result of the voltages in idle mode of PV system

In the next step, short circuit in one phase of the transmission line is simulated. The simulation results of the voltages and currents in short circuit mode of the PV system in Fig. 10 and Fig. 11 are shown.

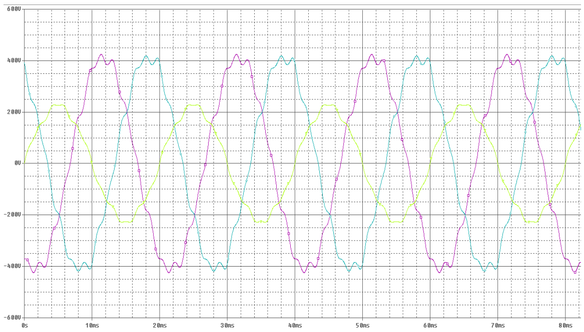

Fig.10. Simulation result of the voltages in short circuit mode of PV system

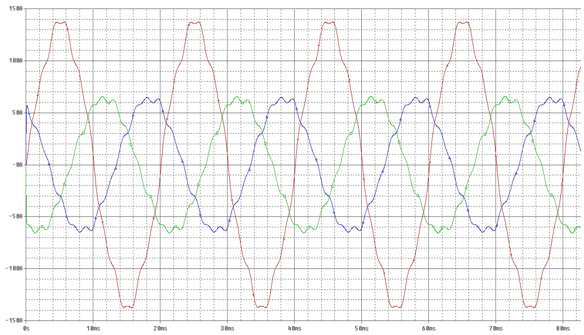

Fig.11. Simulation result of the currents in short circuit mode of PV system

The voltage THD is 6.2%. The currents are above the nominal inverter values. This will trigger the protection and this process will continue in a very short time.

C. Discussion

The performance analysis enables opportunity for determination the optimum operating mode with minimal power losses in the transmission line. This reduces the cost of electricity distribution. Generated power of PV system has an optimal value for the economic efficiency.

The study of electromagnetic compatibility checks requirements of standards and enhances the quality of generated electricity from PV system.

The simulations allow opportunities to study the PV system in emergency modes, which can't be explored without interrupting the investigated system.

VI. CONCLUSION

The analyzed photovoltaic system has a significant advantage - it reduces the cost of transmission and distribution of electrical energy, because the power is produced with low voltage at the end point of use.

The PV system is balanced according reactive power in normal mode. This does not obstruct the low voltage distribution grid with the transfer of reactive power.

The total harmonic distortion of the object is very low and satisfies the requirements of the standards. The electromagnetic compatibility of analyzed small PV power system is satisfied.

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