

Analysis of a single phase inverter for photovoltaic systems operating in a weak electric grid

Gorazd Štumberger, Sebastijan Seme, Klemen Deželak, Andrej Hanžič, Jože Voršič

University of Maribor
Faculty of Electrical Engineering and Computer Science
Smetanova 17, 2000 Maribor, Slovenia
phone: +386 2 220 7075, fax: +386 2 220 7272
e-mail: gorazd.stumberger@uni-mb.si

Abstract. Single-phase inverters for photovoltaic systems are normally analyzed when they are connected to the strong electric grid with low impedance. This work focuses on analysis of a single-phase inverter operating in a weak electric grid with relatively high impedance. Presented are experimentally determined results for the inverter's efficiency, voltage and current total harmonic distortion and power factor. The results presented show substantial contents of sub harmonic components in the inverter's output current.

Key words: photovoltaic system, single-phase inverter, experimental methods, efficiency, power factor, THD

1. Introduction

Operational characteristics of single-phase inverters for photovoltaic systems [1]-[5] are normally determined by tested performed in a strong electric grid with low impedance. However, photovoltaic system can be also connected to the electric grid at the end of radial distribution line which is often the case in rural areas. In this case the grid impedance is relatively high.

In the case study, this work focuses on analysis of a single phase inverter for photovoltaic systems operating in a weak electric grid where impedance is just below one Ohm. In order to eliminate the impact of solar cells and changing solar irradiation on obtained results, the tested inverter is supplied from a DC voltage source. During the tests currents and voltages on the inverter input and output were measured. They were used to determine input and output power of the inverter, its efficiency and power factor. By applying Fourier analysis current and voltage total harmonic distortion is determined. The results presented show high presence of sub harmonic components in inverter output current caused by the maximum power point tracking algorithm.

2. Experimental Set-up

Experimental set-up consists of the tested single-phase inverter, a variable DC voltage source, a transformer, current and voltage measurement chains and a signal processor board dSpace DS 1103 which is used as data acquisition system with sampling frequency 10 kHz.

The inverter's input and output currents were measured by appropriate LEM currents sensors while differential probes were applied for voltage measurement.

The variable DC voltage source consists of an autotransformer, a full wave input rectifier and a capacitor with relatively high capacity. In order to simulate a weak electric grid the tested inverter was connected to the electric grid through a transformer which had the same rated power as inverter.

Different operating points of the inverter, which means different output powers, were set by changing DC voltage on the inverter's input.

3. Analysis

The inverter input voltage u_{DC} and current i_{DC} as well as output voltage u_{AC} and current i_{AC} were sampled with sampling frequency 10 kHz in 1 s long time window. Their RMS values in this window were determined by (1) to (4), while active input and output power were determined by (5) and (6):

$$U_{DC} = \sqrt{\frac{1}{N} \sum_{k=1}^N u_{DC}^2(k)} \quad (1)$$

$$I_{DC} = \sqrt{\frac{1}{N} \sum_{k=1}^N i_{DC}^2(k)} \quad (2)$$

$$U_{AC} = \sqrt{\frac{1}{N} \sum_{k=1}^N u_{AC}^2(k)} \quad (3)$$

$$I_{AC} = \sqrt{\frac{1}{N} \sum_{k=1}^N i_{AC}^2(k)} \quad (4)$$

$$P_{DC} = \frac{1}{N} \sum_{k=1}^N u_{DC}(k) i_{DC}(k) \quad (5)$$

$$P_{AC} = \frac{1}{N} \sum_{k=1}^N u_{AC}(k) i_{AC}(k) \quad (6)$$

where N is the number of samples while k denotes the sample. The RMS values of individual harmonic components were determined by Fourier analysis. They were used to determine THD for inverter input and output currents and voltages. The THD was calculated in two ways. By (7) for fundamental harmonic component 50 Hz and 40 higher order harmonics:

$$THD_{IAC} = \frac{\sum_{h=2}^{40} I_{hAC}^2}{I_{1AC}^2} \quad (7)$$

where I_{hAC} denotes RMS value of inverter output current harmonic component h , and by (8):

$$THD_{IAC} = \frac{I_{AC}^2 - I_{1AC}^2}{I_{1AC}^2} \quad (8)$$

where RMS values of all harmonic components present in inverter output current contribute to the THD. The power factor PF is calculated by (9).

$$PF = \frac{P_{AC}}{U_{AC} I_{AC}} \quad (9)$$

4. Results

Results measured during the tests performed on tested single-phase inverter are presented in Figs.1 to 5 and in Tables 1 and 2. All results are given as functions of output power P_{AC} . Fig. 1 shows RMS values of inverter input DC current I_{DC} and voltage U_{DC} together with input power P_{DC} . Fig. 2 shows RMS values of output current I_{AC} and voltage U_{AC} while power factor PF and efficiency η are shown in Fig. 3.

Figs. 4 and 5 shows voltage and current THD marked as THD_U and THD_I . Fig. 4 shows both THDs determined for fundamental frequency 50 Hz and 40 higher order harmonic components. Voltage and current THDs presented in Fig. 5 are determined for fundamental frequency 50 Hz and all frequencies between 0 and 5 kHz.

The time behavior of inverter's input and output currents, voltages and instantaneous powers as well as amplitude spectra of output current and voltage are shown in Figures 6 to 8.

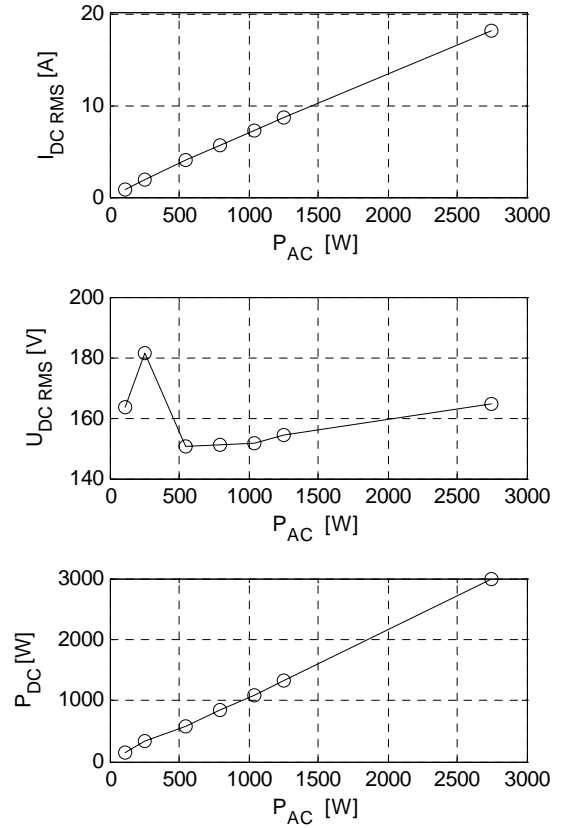


Figure 1: RMS value of input current I_{DC} , RMS value of input voltage U_{DC} and input power P_{DC} measured during tests, given as functions of output power P_{AC}

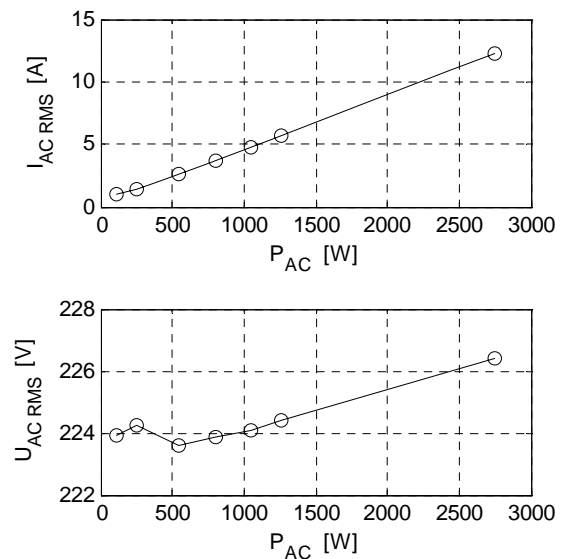


Figure 2: RMS values of output current I_{AC} , output voltage U_{AC} measured during tests, given as functions of output power P_{AC}

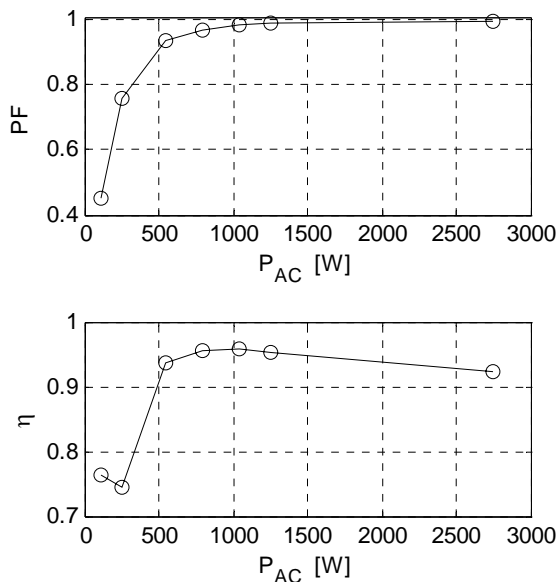


Figure 3: Power factor PF and efficiency η measured during tests, given as functions of output power P_{AC}

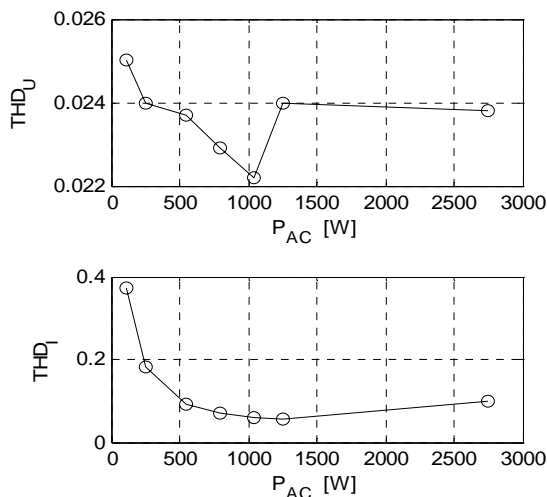


Figure 4: Voltage and current THD for fundamental frequency 50Hz and 40 higher order harmonic components, given as functions of output power P_{AC}

Comparison of current THDs in Figs. 4 and 5 clearly shows that THD presented in Fig. 5 reaches higher value. The reason for this is substantial amount of sub harmonic components in the inverter output current. They are not accounted for when fundamental and higher harmonic components are used to calculate current THD.

5. Conclusion

Analysis of a single-phase inverter for photovoltaic systems operating at weak electric grid is performed in the paper. It is shown that output current of the inverter contains substantial amount of harmonic components lower than 50 Hz. They influence energy transmission and like higher order current harmonic components increase transmission losses. One of the reasons for

appearance of these harmonic components is algorithm for tracking of maximal power.

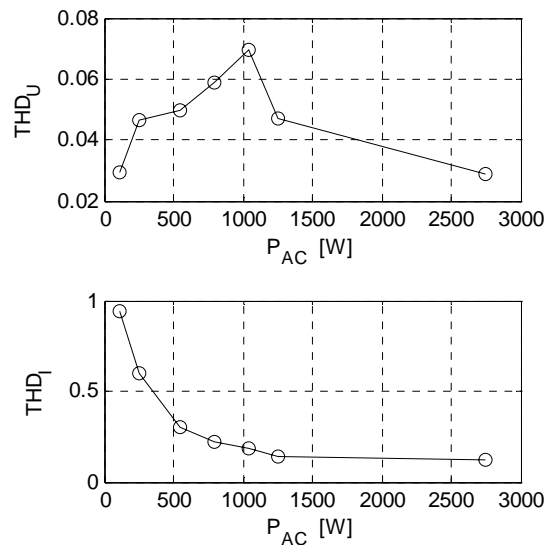


Figure 5: Voltage and current THD for fundamental frequency 50Hz and frequencies 0 Hz to 5 kHz, given as functions of output power P_{AC}

Acknowledgement

This work was supported in part by the ARRS, Project No. L2-7560-1792 and P2-0115.

References

- [1] M. Sidrach-de-Caradona, J. Carretero, *Analysis of the current total harmonic distortion for different single-phase inverters for grid-connected pv-systems*, Solar Energy Materials & Solar Cells 87 (2005), 529-540.
- [2] D. G. Infield, P. Onions, A. D. Simmons, G. A. Smith, *Power Quality From Multiple Grid-Connected Single-Phase Inverters*, IEEE Transactions On Power Delivery, vol. 19, No. 4, October 2004.
- [3] P. G. Barbosa, H. A. C. Braga, M. do C. B. Rodrigues, E. C. Teixeira, *Boost Current Multilevel Inverter and Its Application on Single-Phase Grid-Connected Photovoltaic Systems*, IEEE Transactions On Power Electronics, vol. 21, No. 4, July 2006.
- [4] R. M. Hudson, T. Thome, F. Mekanik, M. R. Behnke, S. Gonzalez, J. Ginn, *Implementation and testing of anti-islanding algorithms for IEEE 929 - 2000 compliance of single phase photovoltaic inverters*, Conference Record of the IEEE Photovoltaic Specialists Conference, 2002, p 1414-1419.
- [5] T-F. Wu, H-S. Nien, C-L. Shen, T-M. Chen, *A Single-Phase Inverter System for PV Power Injection and Active Power Filtering With Nonlinear Inductor Consideration*, IEEE Transactions On Industry Applications, vol. 41, No. 4, July/August 2005.

Table 1: Power, voltage and current measured on inverter input and output, power factor on efficiency given for 7 different operating conditions

	a)	b)	c)	d)	e)	f)	g)
$P_{AC-output}$ [W]	107.33	247.66	543.68	796.98	1043.20	1254.50	2748.00
$U_{AC-output}$ [V] RMS	223.9080	224.2371	223.5745	223.8780	224.0995	224.3813	226.4311
$I_{AC-output}$ [A] RMS	1.0650	1.4622	2.6060	3.6883	4.7553	5.6697	12.2477
$P_{DC-input}$ [W]	140.5772	332.5651	579.9884	833.8860	1087.8	1318.0	2978.9
$U_{DC-input}$ [V] RMS	163.5200	181.5812	150.4855	151.1309	151.7242	154.2427	164.6138
$I_{DC-input}$ [A] RMS	0.8601	1.8336	3.9935	5.6252	7.2561	8.6196	18.1242
PF	0.4501	0.7553	0.9331	0.9652	0.9789	0.9861	0.9909
η	0.7635	0.7447	0.9374	0.9557	0.9590	0.9518	0.9225

Table 2: Current and voltage THD given for frequencies between 50 Hz and 2 kHz and for frequencies between 0 Hz and 5 kHz as a function of inverter output power

	a)	b)	c)	d)	e)	f)	g)
$P_{AC-output}$ [W]	107.33	247.66	543.68	796.98	1043.20	1254.50	2748.00
THD _I : f=50Hz to 2 kHz	0.3718	0.1837	0.0935	0.0692	0.0598	0.0555	0.1005
THD _U : f=50Hz to 2 kHz	0.0250	0.0240	0.0237	0.0229	0.0222	0.0240	0.0238
THD _I : f=0Hz to 5kHz	0.9395	0.5949	0.3026	0.2196	0.1823	0.1426	0.1230
THD _U : f=0Hz to 5kHz	0.0293	0.0464	0.0500	0.0586	0.0693	0.0470	0.0289

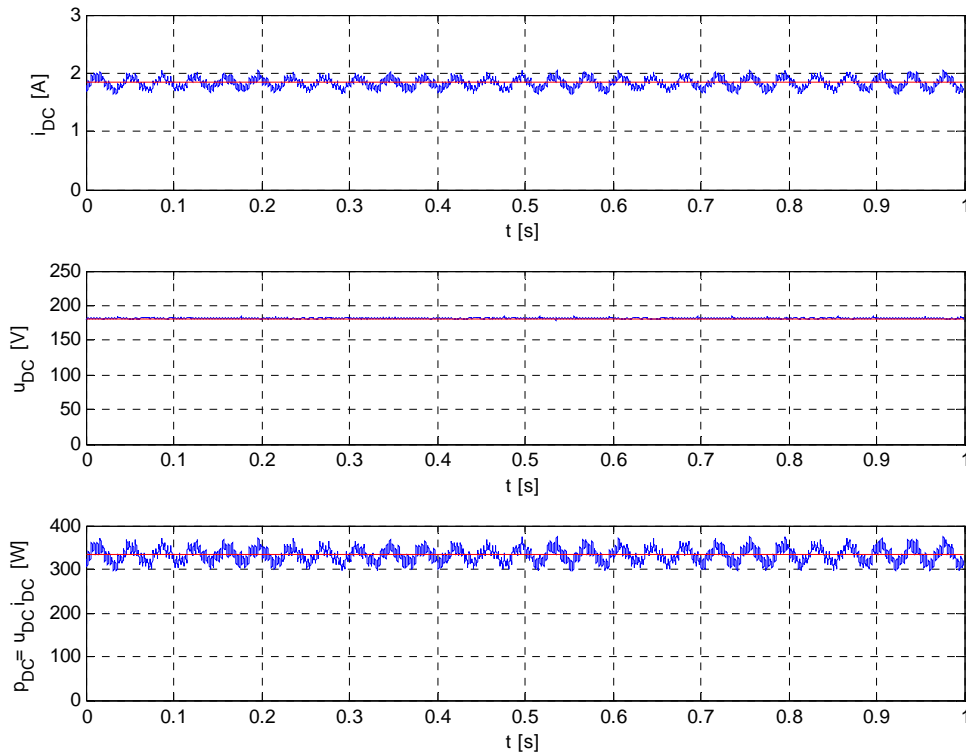


Figure 6: Time behavior of current i_{DC} , voltage u_{DC} and instantaneous power $p_{DC}=i_{DC} u_{DC}$ at the inverter's input at output power $P_{AC}=247.66$ W

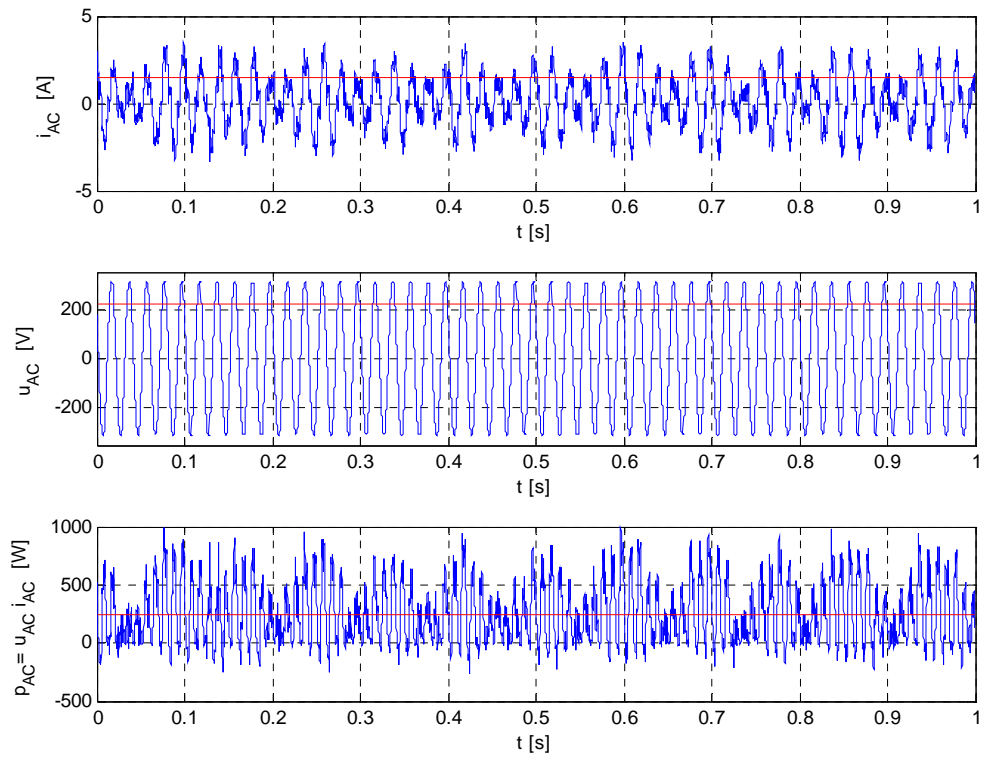


Figure 7: Time behavior of current i_{AC} , voltage u_{AC} and instantaneous power $p_{AC}=i_{AC} u_{AC}$ at the inverter's output at output power $P_{AC}=247.66$ W.

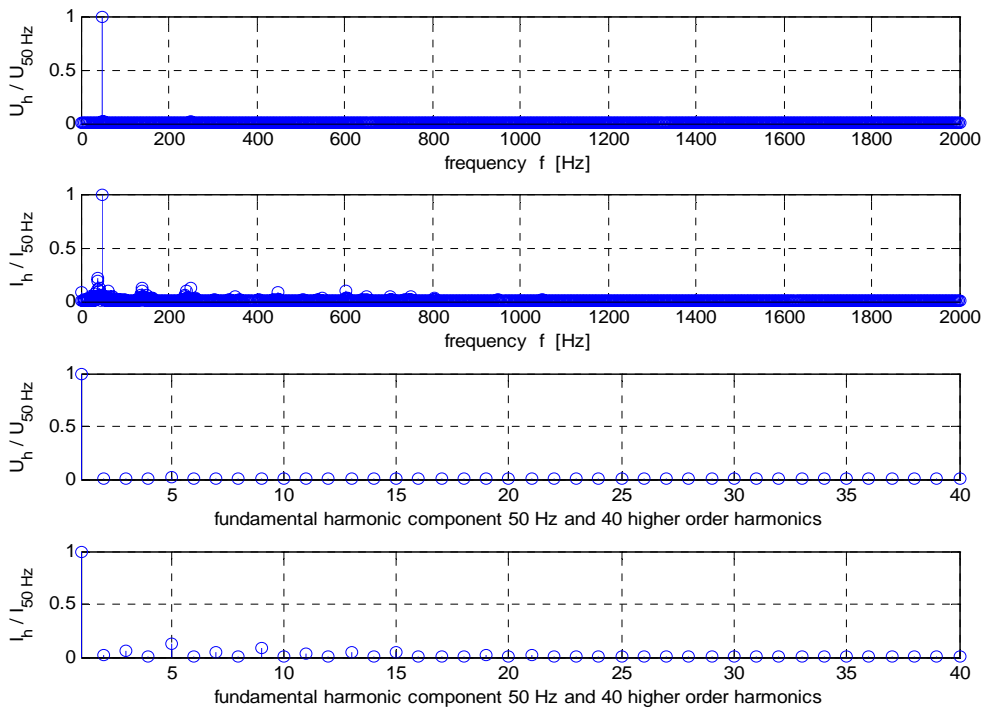


Figure 8: Amplitude spectra of inverter's output current and voltage given in relative format the inverter's output at output power $P_{AC}=247.66$ W.