Electric and Magnetic Fields Due to the Operation of Roof Mounted Photovoltaic Systems

A. S. Safigianni and A. M. Tsimtsios
Electrical and Computer Engineering Department
Democritus University of Thrace, Xanthi, Greece

Abstract— This paper investigates the electric and magnetic fields due to the operation of roof mounted photovoltaic units. In this framework, firstly, basic topological, constructional and operational data of these systems have been provided. Electric and magnetic field measurements in roof mounted photovoltaic systems having different nominal power and inverter types (single or three-phase) have been performed. The main measurement results have been evaluated according to the reference levels for safe public exposure given by international guidelines and relevant conclusions have been finally derived.

1. INTRODUCTION

Exposure to man-made electromagnetic fields has been steadily increasing during the previous century. The benefits of using electricity in everyday life and health care are unquestioned, but during the last years the scientific community as well as the general public have become increasingly concerned about potential health hazards of exposure to electric and magnetic fields (EMFs) at extremely low frequencies (ELF).

These fields have been suspected of causing or contributing to adverse health effects. Although some health effects have been statistically related to ELF EMFs exposure, these effects are poorly understood and may exist only as statistical or scientific errors. The final conclusion of the relevant work done by several expert working groups all over the world is that more research is required in order to give an accurate answer to the question "do ELF EMFs present a human health hazard?"

Nowadays, national standards as well as generally accepted guidelines define reference levels for safe public and occupational exposure to ELF EMFs. Specifically, according to the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [1] guidelines, these levels for safe general public exposure and for the frequency of 50 Hz are:

- For electric field strength, $E < 5\,\mathrm{kV\ m^{-1}}$
- For magnetic flux density, $B < 200\,\mu\mathrm{T}$

The relevant levels for safe occupational exposure are:

- For electric field strength, $E < 10\,\mathrm{kV\ m^{-1}}$
- For magnetic flux density, $B < 1000\,\mu\mathrm{T}$

In Greece, during the last years a huge number of independent producer applications have been submitted and approved, concerning ground and roof mounted photovoltaic (PV) systems connected to the power distribution network. The Greek Government subsidises the production of these 'green' kWhs in order to meet the environmental constraints established by the Kyoto Protocol and other government initiatives primarily concerning fuel saving.

Various researchers have treated extensively the EMFs generated by transmission lines [2, 3], power stations and substations [4–9] of various voltage levels, domestic appliances etc.. Limited data are yet available about the fields of PV units. In particular, the authors of [10] give magnetic field measurements on an alternating current PV module with attached inverters while the authors of [11] give sound pressure level and EMF measurements at three utility-scale sites with solar PV arrays as well as at one residential PV installation but only inside the house. The measured field values in these papers are far below the safe exposure levels.

This paper investigates the EMFs due to the operation of roof mounted PV units. The close proximity of these units to houses and work places causes anxiety among people over possible health hazards from the resultant EMFs. Therefore, first of all, basic topological, constructional and operational data of these systems are provided. EMF measurements in roof mounted PV systems having different nominal power and inverter types (single or three-phase) have been performed. The main measurement results have been evaluated according to the ICNIRP guidelines. Conclusions, concerning safe public exposure to these fields have been finally derived.

2. ROOF MOUNTED PV UNITS AND EMF MEASUREMENTS

The EMF measurements were performed in PV systems mounted on the roof of three residences in the region of Xanthi, Greece which corresponds to the latitude of 41°. These residences are denoted below with the letters A, B and C. The measurements were performed on March 3rd 2013, between 10 : 30 am and 14 : 00 pm. The ambient temperature was around 12°C. The instrument used for the EMF measurements was the EFA — 3 analyser constructed by the Wandel & Goltermann Company, which is able to take field measurements at the frequency range from 5 Hz to 30 kHz. The same instrument was used in [4] where its characteristics are given in detail.

The PV unit mounted on the roof of the residence A has a nominal power of 8.05 kW, it consists of 35 polycrystalline silicon solar panels, with a nominal power of 230 W each and is connected to the distribution network via three single-phase inverters, each one equipped with an isolation transformer and located also on the roof of the residence. The PV unit of the residence B has a nominal power of 4.8 kW, it consists of 20 polycrystalline silicon solar panels with a nominal power of 240 W each and is connected to the distribution network via one single-phase inverter outside the roof. Finally, the PV unit of the residence C has a nominal power of 9.84 kW, it consists of 41 polycrystalline silicon solar panels with a nominal power of 240 W each and is connected to the distribution network via one three-phase inverter outside the roof.

The initial intention was to take magnetic field measurements every 2 m (horizontally and vertically), within the range of frequencies and for three different heights: head height (2 m), waist height (1 m) and roof surface. Indicative measurements carried out showed that the 50 Hz component is dominant making the harmonic components negligible.

The measurement process for the residence A is the following. Figure 2 shows the ground plan of the roof of the Residence A with the positions where it was scheduled to obtain EMF measurements. As shown, three additional positions (A44, A45 and A46) are identified in the inverters, for more detailed measurements, apart from the basic measurement positions (A0–A43). Table 1 shows the measured magnetic flux density values on the roof of the residence A. These values are below the reference level for safe public exposure, which is equal to 200 μT, in all the measurement positions. In most of these positions the magnetic flux density value is extremely low. Specifically, it does not exceed the value of 1 μT whilst the maximum magnetic flux density value was measured in the site of the inverters and it was equal to 118 μT. The isolation transformers of these inverters are an additional reason for the increased magnetic flux density value in this case. Only in four positions and for the height of 2 m, it was impossible to take field measurements because solar panels exist there. No serious differentiation was noted in the measured magnetic flux density values in relation to the height, as Table 1 shows. As a consequence, the only measurements performed thereafter in the residences B and C correspond to the height of 1 m. Magnetic field measurements were also performed in other places of the residence where its residents have activities, but the resulting values were negligible. During the measurement process in the residence A, the power of the PV unit was equal to 6.4 kW.

All the measured magnetic flux density values in residences B and C were far below the reference level for safe public exposure. In particular, in the residence B, the measured values at the grid positions on the roof were between 0.32 μT and 0.52 μT, whilst the maximum magnetic flux density value was measured at the inverter position, outside the roof and it was equal to 24 μT. In the

Figure 1: Photo view of the roof of the residence A.

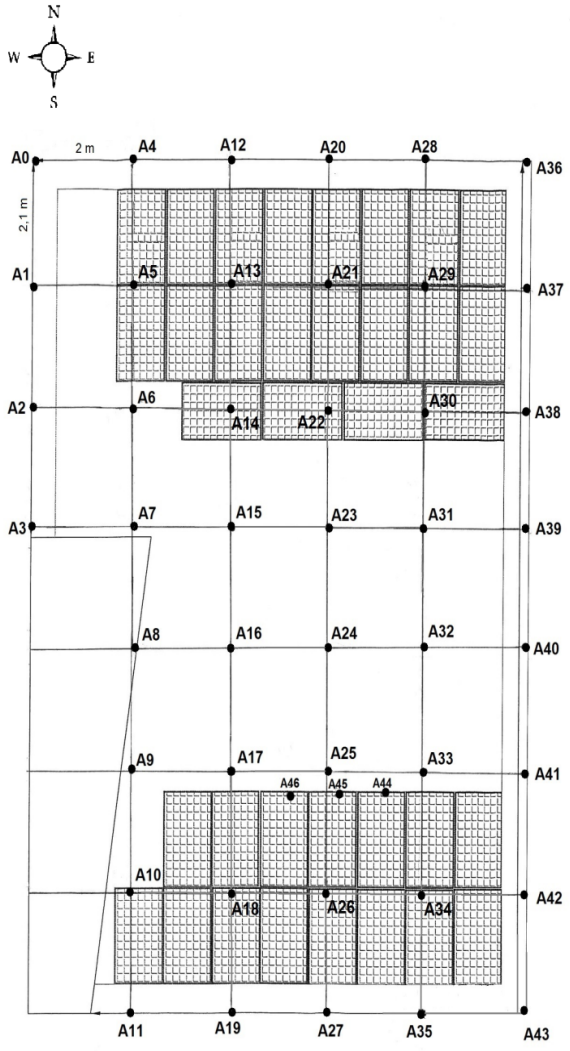

Figure 2: Ground plan of the roof of the residence A with the measurement positions.

	rms magnetic flux density values B, (μT)		
Measurement position	0m	1m	2m
A0	0.37	0.30	0.33
A1	0.32	0.38	0.38
A2	0.37	0.33	0.33
A3	7	0.31	0.35
A4	0.36	0.30	0.33
A5	0.36	0.36	-
A6	0.43	0.32	0.52
A7	0.35	0.37	0.38
A8	0.44	0.30	0.35
A9	0.30	0.34	0.34
A10	0.35	0.36	0.34
A11	0.35	0.36	0.34
A12	0.32	0.35	0.38
A13	0.36	0.38	-
A14	0.35	0.36	0.41
A15	0.35	0.37	0.35
A16	0.44	0.30	0.35
A17	0.40	0.32	0.34
A18	0.35	0.36	0.34
A19	0.35	0.36	0.34
A20	0.29	0.28	0.39
A21	0.37	0.32	-
A22	0.47	0.49	0.33
A23	0.43	0.39	0.41
A24	0.44	0.30	0.35
A25	0.44	4.20	1.80
A26	0.35	0.36	0.34
A27	0.35	0.36	0.34
A28	0.30	0.33	0.36
A29	0.33	0.34	-
A30	0.45	0.33	0.37
A31	0.43	0.32	0.41
A32	0.44	0.30	0.35
A33	0.35	3.50	0.45
A34	0.35	0.36	0.34
A35	0.35	0.36	0.34
A36	0.41	0.29	0.28
A37	0.37	0.31	0.30
A38	0.30	0.33	0.36
A39	0.43	0.32	0.41
A40	0.53	0.55	0.33
A41	0.64	0.66	0.38
A42	0.35	0.36	0.34
A43	0.35	0.36	0.34
A44	0.34	118	0.85
A45	0.34	113	0.85
A46	0.34	108	0.85

Table 1: Magnetic flux density values in the PV unit of the residence A.

residence C, the measured values at the grid positions on the roof were between 0.32 μT and 1.2 μT, whilst the maximum magnetic flux density value was also measured at the inverter position, outside the roof and it was equal to 12 μT. The measured magnetic flux density values in other positions inside the residences B and C were negligible. During the measurement process in residences B and C, the power of the PV units was 4.6 kW and 8.4 kW respectively.

Concerning the electric field strength measurements, the electric field sensor was placed on a tripod at the height of 1.7 m, at several measurement positions in each residence and it was connected to the main instrument with a 10 m fiber optic cable. This connection and the distance between the sensor and the main instrument were necessary in order to ensure that the electric field strength would not be perturbed by the presence of persons. In none of the residences the total number of scheduled electric field strength measurements was performed, because indicative measurements that were taken showed that the electric field strength was not differentiated significantly with the measurement position. The measured electric field strength values in all the residences were extremely lower than the reference level for safe public exposure, which is equal to 5 kV/m. Specifically, in the residence A, the entire electric field strength values were around 2 V/m, except for one point, where a cable passes and this value was equal to 28.9 V/m. In the residence B the entire measured electric field strength values were between 22 and 36 V/m. In this case, the

electric field was relatively higher because a low voltage distribution network exists very close to this residence. The measured values at the inverter position were very low. In the residence C the entire measured electric field strength values were between 2.2 and 3 V/m, while at the inverter position 2 V/m were measured. Electric field measurements were also performed in other places of the residences, but the resulting values were negligible.

During the measurement process, all three examined PV units were operating close — but lower than their nominal power. However, even if the measured magnetic flux density values were extrapolated to the nominal power of the PV units, the resulting values would also remain far below the relevant reference level for safe public exposure.

3. CONCLUSIONS

In recent years, the general public and working personnel have become increasingly concerned about the health hazards of exposure to ELF EMFs. National and international guidelines have enacted reference levels for safe exposure, while researchers from different areas of expertise deal with the above-mentioned health effects.

This paper reports the results of electric and magnetic field measurements in roof mounted PV systems having different nominal power and inverter types. The measurements have been performed in order to determine whether internationally accepted reference levels for safe public exposure are violated. Both these measurements and the elaboration of the relevant results showed that the magnitudes of the measured field values are within recognized guidelines, suggesting that these fields are not dangerous and, therefore, are no cause of concern among the public.

REFERENCES

1. International Commission of Non Ionizing Radiation Protection (ICNIRP), "ICNIRP statement-guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz)," *Health Physics*, Vol. 99, No. 6, 818–836, 2010.
2. Filippopoulos, G. and D. Tsanakas, "Analytical calculation of the magnetic field produced by electric power lines," *IEEE Trans. on Power Delivery,* Vol. 20, No. 2, 1474–1482, 2005.
3. Faria, J. A. and M. E. Almeida, "Accurate calculation of magnetic-field intensity due to overhead power lines with or without mitigation lops with or without capacitor compensation," *IEEE Trans. on Power Delivery*, Vol. 22, No. 2, 951–959, 2007.
4. Safigianni, A. S. and C. G. Tsompanidou, "Measurements of electric and magnetic fields due to the operation of indoor power distribution substations," *IEEE Trans. on Power Delivery*, Vol. 20, No. 3, 1800–1805, 2005.
5. Joseph, W., L. Verloock, and L. Martens, "General public exposure by ELF fields of 150-36/11-kV substations in urban environment," *IEEE Trans. on Power Delivery*, Vol. 24, No. 2, 642–649, 2009.
6. Paraskevopoulos, A. P., P. D. Bourkas, and C. G. Karagianopoulos, "Magnetic induction measurements in high voltage centers of 150/20 kV," *Measurement*, Vol. 42, No. 8, 1188–1194, 2009.
7. Safigianni, A. S. and C. G. Tsompanidou, "Electric and magnetic field measurements in an outdoor electric power substation," *IEEE Trans. on Power Delivery*, Vol. 24, No. 1, 38–42, 2009.
8. Korpinen, L., H. Kuisti, R. Pääkköen, P. Vanhala, and J. Elovaara, "Occupational exposure to electric and magnetic fields while working at switching and transforming stations of 110 kV," *Annals of Occupational Hygiene*, Vol. 55, No. 5, 526–536, 2011.
9. Safigianni, A. S., A. I. Spyridopoulos, and V. L. Kanas, "Electric and magnetic field measurements in a high voltage center," *Annals of Occupational Hygiene*, Vol 56, No. 1, 18–24, 2012.
10. Jennings, C., G. Chang, A. Reyes, and C. Whitaker, "AC photovoltaic module magnetic fields," *26th Photovoltaic Specialists Conference*, Anaheim, USA, Sept. 30–Oct. 3, 1997.
11. Guldberg, P. H., "Study of acoustic and EMF levels from solar photovoltaic projects," INCE, CCM, Tech. Environmental Inc. for Massachusetts Clean Energy Center, 2012.