Monitoring of 20 kWp photovoltaic system

Milan Belik

ABSTRACT

The document describes influence of basic meteorological value to proposition of photovoltaic arrays. Results from 3 years long measurements on demonstration system are displayed in supporting figures and tables. Next part features experiences gained during installation and trial run of 20 kWp photovoltaic system installed on the roof of new building of Faculty of Electroengineering in Pilsen. Time distributions of electrical values containing information about interactions between supply network and monitored system are presented in figures and resolved.

1. INTRODUCTION

During construction of new University's building in 2003, large photovoltaic array was installed on flat roof of the building. Installed system, that is connected to public grid, supplies 20 kW peak output and till lately was the largest system operated in Czech Republic.

The main system consists of 192 monocrystalline silicon solar cells fields manufactured by Solartec and 8 single-phase DC/AC converters SunProfi. The solar array composes balanced architectonic unit with the new building and demonstrates aesthetic value of solar cells as architectural elements. Power consumption of the inverters is covered by solar system itself and the output is symmetrically phased to building's supply network on 230V/400V level. This solution of connection to grid was chosen because of additional costs of own block transformer and appropriate ducts. Very important components of this system are precise sensors of solar irradiance and outer conditions, sophisticated measuring chain for output values monitoring and public demonstrational panel. The second part of the system is a special experimental tracker with adjustable elevation that can be operated and monitored separately to research influence of elevation, day time and year season to maximum power output.

2. PHOTOVOLTAIC SYSTEM PROPOSITION

Before construction of the new building and photovoltaic system, 3 years long measurement was executed. The very first researched task was determination of basic operational conditions in specified locality – that means measurements of solar irradiance, atmosphere pollution factor and solar exposure times. This research was cooperated with ZCE (local energy distribution company). Following data analysis resulted into predictable seasonal energy margins and reachable power productions.

The continuous measurement of basic meteorological values took 3 years. Real values of solar irradiance, atmosphere pollution factor and solar exposure times were recorded in 1 minute period. As primary model there was used demonstration solar system in installed in the center of City of Pilsen. The measurement was made in cooperation with ZCE (local energy distribution company).

The measurement system consisted of solar sensor RS 81-I (SG420) and data logger Comet MS3. The special solar irradiance sensor was installed in the middle of the face of solar thermal collector array. The collectors were situated southbound and mounted in angle 45°. The location was in the yard of the Custom Center and was partially shaded with full-grown trees and surrounding buildings. From this reason we can distribute the gained results into two categories. In first cluster there are values valid only for this concrete location and the other cluster contains general values valid for whole city of Pilsen.

Characteristic time distributions of solar irradiance for each year season are displayed on Figure 1 – Figure 4. Detailed daily cut-outs comparing characteristic sunny and cloudy days in each season are shown on Figure 5 – Figure 8.

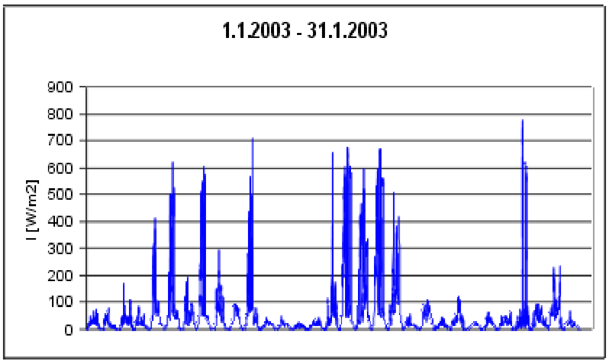

Fig. 1.: Winter season

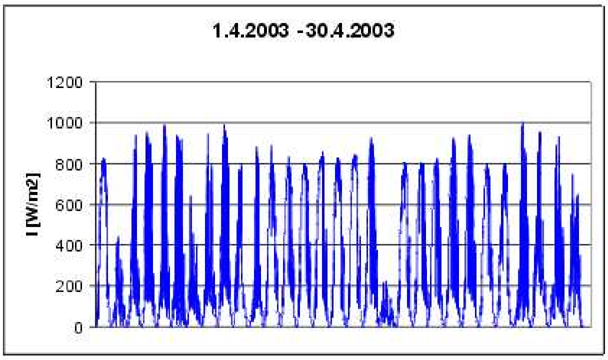

Fig. 2.: Spring season

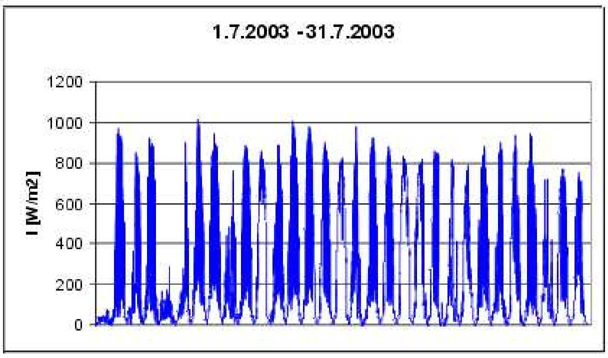

Fig. 3.: Summer season

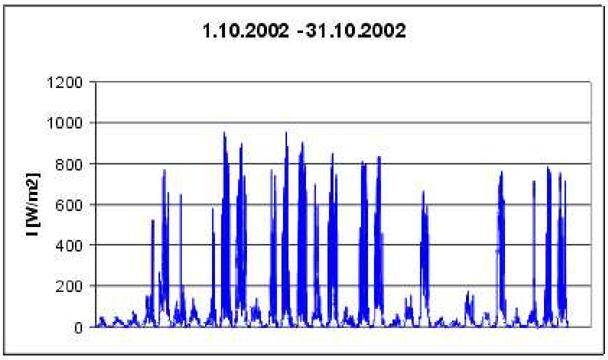

Fig. 4.: Autumn season

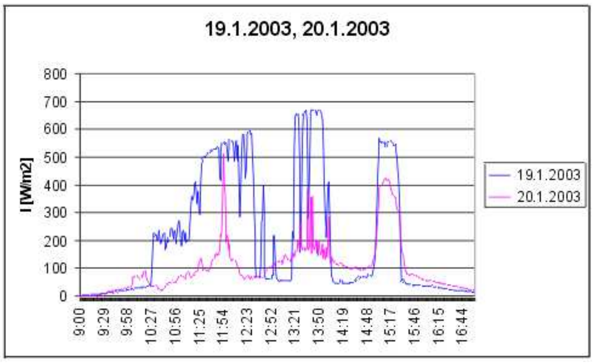

Fig. 5.: Winter days comparison

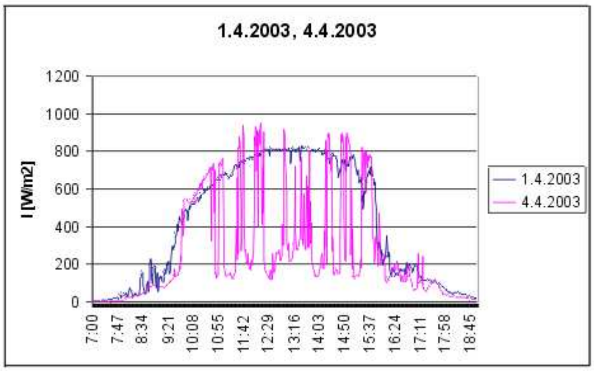

Fig. 6.: Spring days comparison

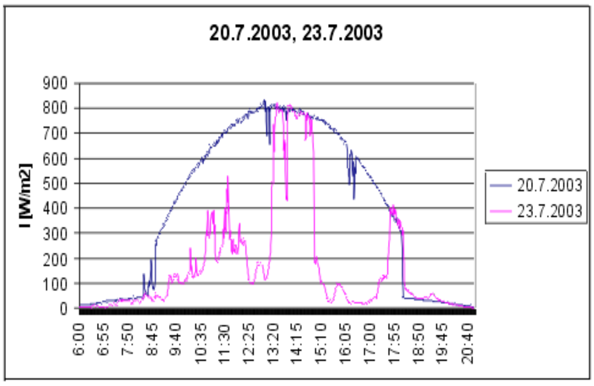

Fig. 7.: Summer days comparison

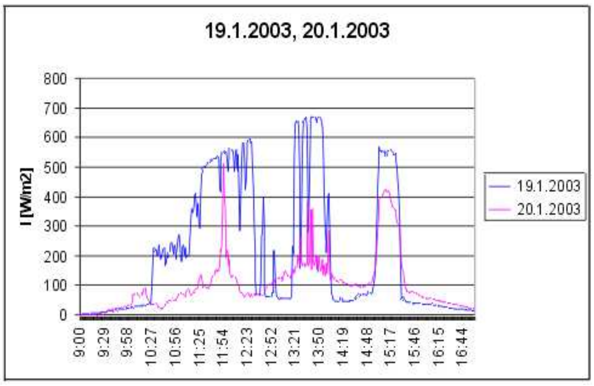

Fig. 8.: Autumn days comparison

From these time distributions there were calculated approximately estimated energy gains for each year season and air pollution factor. Basic equations for estimated energy gain:

$$E = \int_0^T I(t)dt \tag{1}$$

Table I shows monthly average, minimal and maximal daily averages of solar irradiance for each month. These values are computed as averages from all years. The values are compared to theoretical values valid for Czech Republic. Lower rows of the table show monthly average, minimal and maximal daily averages of estimated energy gain for each month. These values are again compared to theoretical values valid for Czech Republic.

Table I: Average Solar irradiance and Estimated energy

	I.	II.	III.	IV.	V.	VI.	VII.	VIII	IX.	X.	XI.	XII.
I_{teor} [W/m^2]	412	490	558	580	600	590	600	580	558	490	412	344
I_{ef}[W/m^2]	388	456	551	564	589	587	582	565	541	482	398	322
I_{max} [W/m^2]	407	471	553	571	602	589	586	573	552	485	403	329

I_{min} [W/m^2]	381	449	448	557	586	583	579	560	532	476	390	315
E_{teor} [kWh/m^2]	3,40	4,96	6,70	8,06	9,42	9,64	9,42	8,06	6,70	4,96	3,40	2,70
E_{ef} [kWh/m^2]	3,21	4,72	6,12	7,54	8,32	9,26	9,11	7,87	6,45	4,51	3,12	1,98
E_{max} [kWh/m^2]	3,37	4,89	6,56	8,01	8,99	9,58	9,38	7,99	6,54	4,83	3,33	2,15
E_{min} [kWh/m^2]	3,12	4,68	6,04	7,17	8,01	9,01	8,78	7,64	6,38	4,32	3,03	1,78

These results were used for precise calculation of air pollution factor. This factor Z shows, how many atmosphere layers can make the same reduction of solar irradiance as the atmosphere in the researched case and could be calculated using Linke's equation for air pollution factor:

$$Z = \frac{\ln I_0 - \ln I_N}{\ln I_0 - \ln I_Z} \qquad (2)$$

where I_0=1360 W/m2 (solar constant), I_N is solar irradiance on horizontal plane while researched air pollution and I_Z is solar irradiance on horizontal plane while clean air (theoretical value).

Table II shows computed values of air pollution factor. The values are monthly average, minimal and maximal daily averages of solar irradiance for each month. The values are compared to theoretical values valid for Czech Republic. For better comparison of Pilsen's air quality there are shown theoretical values valid for industrial city (like Pilsen is), agricultural village and natural mountains.

Table II: Air Pollution Factor

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
Z_{ef}	3,15	3,21	3,04	3,10	3,07	3,02	3,11	3,09	3,10	3,05	3,09	3,14
Z_{min}	3,03	3,12	3,03	3,06	2,99	3,01	3,09	3,04	3,04	3,03	3,06	3,10
Z_{max}	3,20	3,26	3,74	3,14	3,09	3,04	3,13	3,12	3,16	3,09	3,14	3,19
Z_{city}	3,10	3,20	3,50	4,00	4,20	4,30	4,40	4,30	4,00	3,60	3,30	3,10
$Z_{village}$	2,10	2,20	2,50	2,90	3,20	3,40	3,50	3,30	2,90	2,60	2,30	2,20
$Z_{mountains}$	1,50	1,60	1,80	1,90	2,00	2,30	2,30	2,30	2,10	1,80	1,60	1,50

3. CONNECTION OF PV SYSTEM TO SUPPLY NETWORK

After installation of the new photovoltaic system on the roof of new faculty building and its connection to public grid trial operation followed. The system has 20kW peak output and till lately it was the largest system operated in Czech Republic. The photovoltaic array consists of 192 dark blue monocrystalline silicon solar cells fields manufactured by Solartec (largest producer of PV cells in Czech Republic). This specific color of cells was choosen because of the best efficiency of these cells and because of architectonic reasons. The array is mounted on flat roof, situated southbound and inclined in 45° angle. The fixed inclination is compromise for full year operation and low purchase costs.

Beside the power circuit the second very important part of the installed system is measuring chain. Values of global solar irradiance, solar irradiance on array's plane, array's temperature, outer temperature, humidity and electrical values such as DC and AC voltage and current can be measured and continuously recorded. Of course other importnant meteorological values are monitored too.

Interesting part of the experimental equipment is computer controled tracker, that can be set in any elevation gaining appropriate values of output power and tracker's plane solar irradiance. Beside these experiments the influence of air pollution on solar cells efficiency was monitored. There were installed 3 couples of solar panels in 3 inclinations (30°, 45°, 60°). One half of each couple was periodicaly cleaned, while the second half was left for weather conditions. This experiment should documentate self-cleaning ability of photovoltaic system.

The most important measurement is performed on influence on supply network. The photovoltaic system produces DC voltage up to 400V (depending on operational point), that is converted by 8 1-phase invertors SunProfi SP-2500 into 3x230V. The connection to building's network is directly through switchboard. Own block transformer is not used because of lowering purchase costs. The photovoltaic array installed on the roof is shown on Figure 9 and used inverters are shown on Figure 10.

Fig. 9.: Pholovoltaic array

Fig. 10.: Inverter room

During trial period the main task was to confront basic operating conditions with EN 50160 standard. This standard defines the electromagnetic compatibility and maximal influence of any equipment to supply network. Based on time distributions got from previous basic measurements, it was decided, that the exemplary operational measurements should be undertaken only for standard operational conditions, that means “constant” level of solar irradiance about 800 W/m^2, exterior temperatures about 20°C, forceless wind and weak cloudiness.

In fact the measurements were executed during warm summer morning using real-time analyser Unipower U900F. In 1 minute periods there was logged output voltage and current in each phase, total output (P, Q, S), power factor, phase unbalance, flicker, total harmonic current deformation and total harmonic voltage deformation. Tested photovoltaic system was measured in almost ideal operating conditions, so that reached results matched in most cases to EN 50160 standard. Only voltage in phase L1 exceeds the limits. Correct solution should be reduction of voltage on the transformer.

These results were used as inputs for Fourier analysis. This operation shows spectral components of emitted voltage and current. For the analysis there were used samples logged in 1 minute periods. The analysis were made up to 50th harmonic. This depth is required by standard EN 50160.

Averages of spectral components from all analysed samples are shown on Figure 11 (voltage) and Figure 12 (current). For better visualization there is not displayed value of 1st harmonic (50Hz).

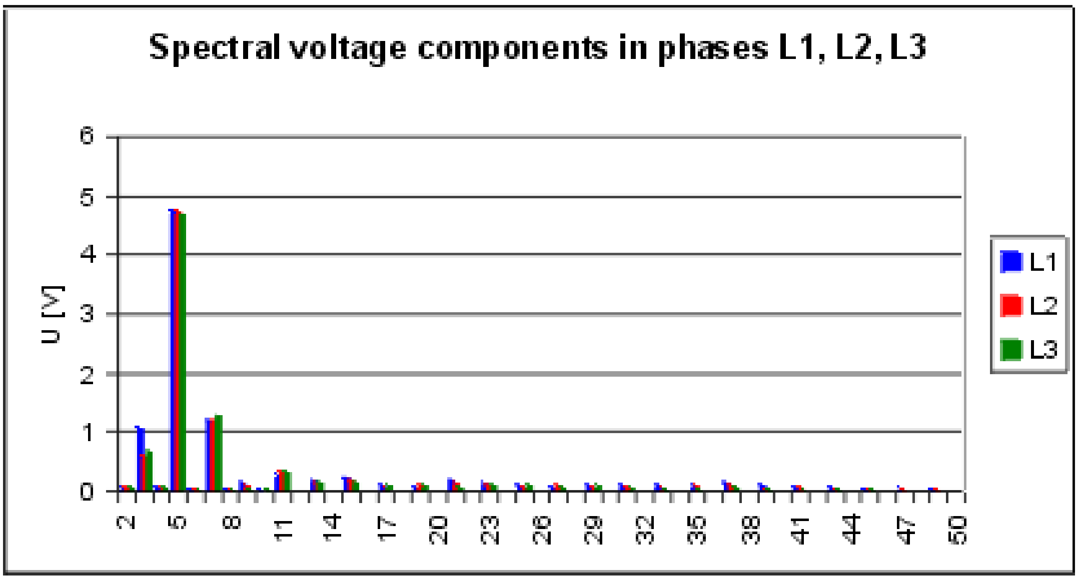

Fig. 11.: Average voltage spectrum

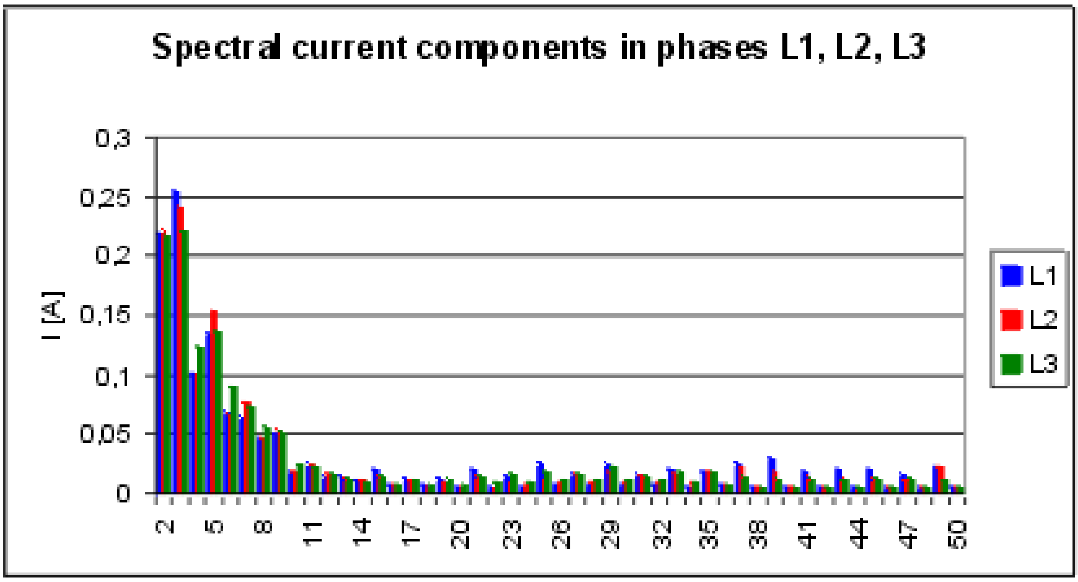

Fig. 12.: Average current spectrum

4. CONCLUSION

Although these results are very useful, because of almost no experiences with operating large photovoltaic systems in Czech Republic, more interesting results should give following measurements. These presented measurements were made while almost ideal operating conditions for photovoltaic systems. That means “constant” and “high” level of solar irradiance and “good” weather conditions.

Even thought the system passed the trial operation and corresponds to EN 50160 standard, there should sometimes arise some anomalous situations. Depending on circumstances in supply network and outer conditions the system could get unstable. Fast changes of general values or operating on lower edge of operation efficiency could cause repeated phasing with adverse reactions and electromagnetic interference with another devices. Understanding these processes during transient phases is the task for future.

5. REFERENCES

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