Influence of Large-Scale Installation of Energy Saving Lamps on the Line Voltage Distortion of a Weak Network Supplied by Photovoltaic Station

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***Abstract*—The aim of this research is to calculate and analyze the harmonic distortion extent caused in weak low-voltage networks due to a possible large-scale installation of the widely spread compact fluorescent lamps (CFLs). The research uses data from laboratory measurements of the produced harmonic currents by CFLs, as well as field measurements of the harmonic content and other characteristic measurements of the electric network of a small Greek island, which is supplied by an autonomous photovoltaic (PV) station. The PV station is also a harmonic generator by itself. This fact combined with other highly nonlinear loads—such as CFLs—causes serious problems at the network power quality as undesirable harmonic components are induced. The whole network is simulated and three scenarios of CFL installation extent are considered, so that the harmonic flow analysis reveals the influence in the power quality. It is examined whether this weak low-voltage electric network is able to keep the total harmonic distortion factor at all nodes under 8%, as more and more CFLs are installed. The conclusions drawn from this analysis are important and must be taken into account in every electric network design.**

***Index Terms*—Fluorescent lamps, harmonic analysis, harmonic distortion, photovoltaic power systems, power quality.**

I. Introduction

THE ELECTRIC power utility companies worldwide suggest the use of energy-saving lamps. The most common type of such lamps is the self-ballasted compact fluorescent lamp with electronic gear. However, that type of lamp is a highly nonlinear load producing extremely distorted current with a total harmonic distortion (THD) usually exceeding 100%.

The market promotion of such lamp types is expected to deteriorate the power quality of the electric network (especially weak ones), given the additive influence of other harmonics sources (electronic equipment, etc). Therefore, steps toward large-scale installation of such energy-saving lamps must be thoroughly studied and analyzed especially on case studies like weak low-voltage networks where the THD content is already high. Otherwise, the result of an expanded use of compact fluorescent lamps (CFLs) will most probably be the increase of voltage THD factor beyond the internationally set limits [1], [2], a fact that causes serious problems to the customer side.

Grid-circulating harmonics is an issue of great importance. International standards define harmonic distortion limits under which the energy producing companies are obliged to operate. It is known that high harmonic existence represents a possible source of faults and troubles for loads and for the electric system equipment. This is the reason why all electric power providers try to maintain high-power quality (stable frequency and voltage as well as nondistorted waveforms). All harmonic sources and effects have been well identified and presented [3]–[7].

On the field of the harmonic content of CFLs or the behavior of CFLs under various exploitation conditions, a large number of papers have been published [8]–[13]. On the contrary, not many studies are published dealing with the influence of CFLs to the power network or with the definition of their maximal presence without leading to excessive voltage distortion [14]–[16].

The principal goal of this research is to identify the levels of the harmonic distortion caused in weak low-voltage networks due to large-scale installation of CFLs. For the purposes of this investigation, the network of a small Greek island of Aegean Sea, named "Arki," was selected. The network is supplied by a 25-kWp autonomous photovoltaic (PV) power station.

The population of the island reaches 100 inhabitants. The PV station uses a self-commutated DC/AC inverter, which is considered to be an important harmonic source [17]–[19]. It has been proved that the harmonic content of the voltage waveform at nodes of the electric network was richer in harmonics when the PV station was on, rather than when the backup diesel generator supplied the system [19].

Elimination techniques used for these harmonics are many and they are applied successfully in most cases in the photovoltaic systems [20], [21]. These techniques are either electronic or conventional. The electronic ones like the sinusoidal pulse-width modulation (SPWM) or the multiple pulse-width modulation (MPWM) are used in almost all new inverter models and their task is to modify and adjust the thyristor pulses in a way that the first harmonic component at the output is of high frequency, thus easy to be filtered. Conventional harmonics reduction techniques like specific transformer connections and filtering are used in old inverter topologies like the one studied in the Arki island. This is the reason why a relatively high THD (2.5–4.5%) of the line voltage is present.

After the PV station, other nonlinear loads produce more harmonic currents that circulate in the power network and when

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added with other harmonic currents of similar phase serious problems on electrical appliances can occur.

The paper applies a three-phase harmonic flow analysis in order to determine the influence of the CFL installation in the power quality of the system. The whole electric network is simulated and three scenarios of CFL installation extent are considered.

Field measurements on the network and the PV station provided the necessary data for the simulation of the electric network. The harmonic content of the line voltage was measured at the output of the PV station and at several places of the network. Furthermore, energy audits determined the installed load and the energy consumption in various typical buildings of the island. On the other hand, laboratory tests were performed on widely used types of CFLs for the measurement of their electrical characteristics and their harmonic spectrum.

II. Arki Island Energy Audit

The 25-kWp PV power plant that supplies the weak low-voltage electric network of the island of Arki has 688 panels in total (43 series of 16 panels each), while each panel consists of 40 solar cells of Photon Technology in series and has a nominal power of 26 Wp.

The PV station of the island is equipped with a three-phase static inverter, which serves the purpose, to feed ac consumers that require 230/400-V supply voltage. More specifically, it is a self-commutated inverter model of AEG "G 220 D 400/43/2 rgf-V30." The dc input supply voltage is 220 V (+/−15%), the rated ac voltage is 3 × 400 V (full load neutral) and the rated power is 24 kW with unity power factor. Its efficiency lies in the range of 73%–91% when the load varies between 10–100%.

The power-electronic section consists of six thyristor stacks combined into two six-pulse three-phase full-wave bridge circuits. That means that each three out of the six identically assembled low-loss McMurray circuits form a three-phase full-wave bridge circuit configuration. With periodic sequence of triggering the main thyristors, each three-phase full-wave bridge circuit supplies a separate three-phase ac system, while the second system lags in time by 30° with respect to the first system. The electric power is transmitted by means of two transformers; one assigned to the first system and the other one to the second but both ending at a common secondary winding.

The inverter has been already presented and simulated in [19]. A simplified single-phase circuit is shown in Fig. 1. The main components of a McMurray circuit are the main thyristors ($V_1 - V_2$), the commutation thyristors ($V_3 - V_4$), the reverse current diodes ($V_5 - V_6$), and the commutation components (C_1, L_1). The main thyristors carry the load current. These periodically triggered into conduction by a pulse train consisting of three rectangular pulses. The block width of the single phase fundamental waveform of the voltage across a primary winding of the associated transformer amounts to 120° at full control. By triggering the thyristor groups in a suitable way, the fundamental block can be split up into two partial blocks laying symmetrically to each other, and being variable in width without that the phase position of the fundamental waveform changes. In this way, the thyristor stack becomes a control element, which is used to control the output voltage.

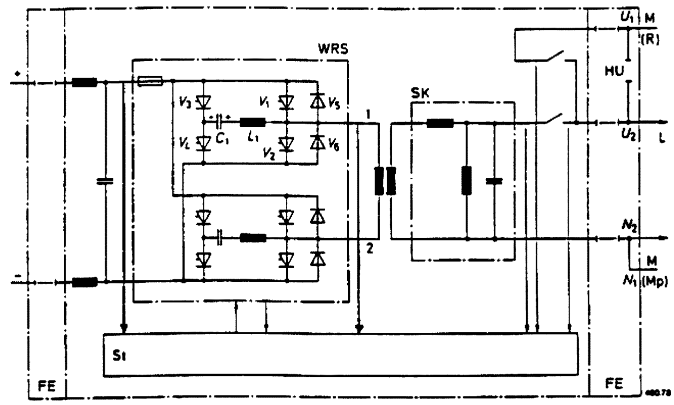

Fig. 1. Simplified (single-phase) diagram of the inverter of the PV station.

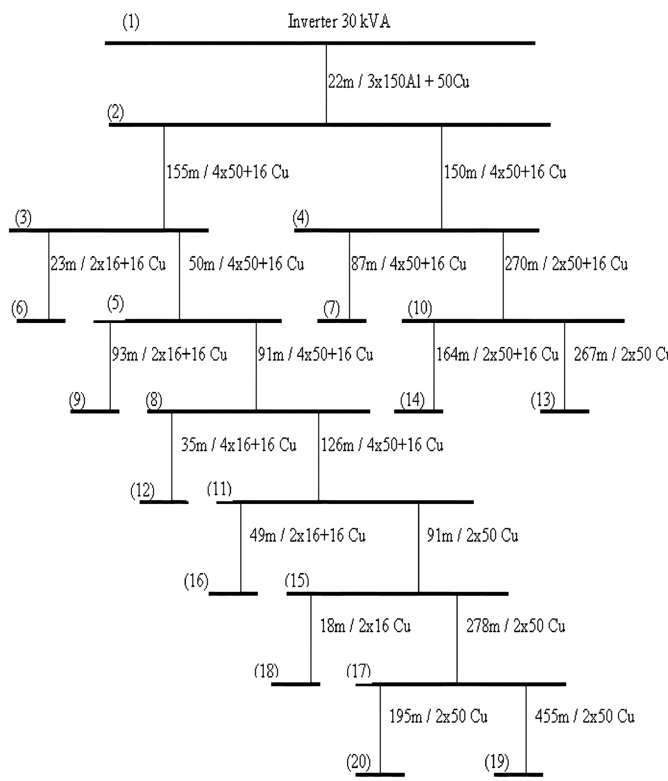

Fig. 2. Topology of the electric network of Arki island.

The electric power is delivered from the PV station to the loads exclusively using overhead lines. The low-voltage network topology of the island along with the data of the overhead lines (conductor type and length) are presented in Fig. 2. The network supplies 60 houses.

The Public Power Corporation (PPC) of Greece does not allow high energy demanding electrical appliances. PPC also suggests gas for cooking, solar panels for hot water, and oil heaters for heating in order to minimize the electrical loads. The most used electrical appliances are incandescent lamps and other low power, home appliances. Load statistical data of the

TABLE I
HARMONIC SPECTRUM (%) OF THE VOLTAGE AT THE PV STATION

Fund	3rd	5th	7th	9th	11th	13th	15th	17th	19th
100	0.9	2.2	0.3	0.1	1.3	1.8	0.3	0.3	0.0

island of Arki show that the load profile of each house consists of lighting (50%) and other consuming appliances (50%).

Field measurements at typical residences showed that the average daily loading (200 W–400 W) was lower than the installed load. It was also observed that there is a load-asymmetry between the three phases. Actually, almost 40% of the load is supplied by the S and T phases. This has been taken into account while simulating the load in the three-phase network. The existing harmonic distortion of the line voltage was also measured at several sites of the island.

III. Field Measurements

Apart from the PV power station, the demand of the island can be covered by a diesel station, which operates only in emergency cases (too many cloudy days, PV station service, etc). It has been observed that the harmonic content was significant at the output of the specific PV station inverter, while—as expected—it was very low when the diesel station was on. The voltage and current THD measurements were performed after connecting the PV station and disconnecting the diesel and vice-versa [19].

Measurements were also performed at numerous preselected lines of the electric grid and at houses and other customers as presented in [19]. The measuring instrument was the Multiver 3S of Dossena. The measurements were being obtained every 500 μs (2 kHz) in each sample procedure. Each sample contains three voltage and four current "sub-samples." The analysis of the samples was performed using the fast Fourier transform (FFT) method. The appropriate software enabled an analysis of harmonic components up to the 19th order (0–950 Hz).

Given the fact that the PV plant injects harmonics into the grid, it is obvious that the harmonic distortion at the output of the PV station is a very important input data for the purposes of the simulation. The voltage harmonic spectrum at the output of the PV station was recorded at several loads during different times and days. After statistical analysis of these measurements, the harmonic spectrum that represents most accurately the harmonic voltage condition at the output of the PV station is shown in Table I.

For the determination of the voltage THD, the IEEE definition was used

$$\mathrm{THD}_v = \frac{\sqrt{V_2^2 + V_3^2 + \ldots + V_N^2}}{V_1} \cdot 100 \qquad (1)$$

where V_1 is the root mean square (rms) value of the fundamental and V_N is the rms value of the N-order harmonic component.

The line voltage waveform was recorded at several nodes of the electric grid of the island. The THD was found to vary in the range 1.85%–5.30% [19]. The higher values of THD indicate that there are certain points of the electric grid where THD exceeds the limits. It should be noticed that the total load demand was 8.5 kW in that period of time (i.e., considerably lower than the installed power of the PV system). This proves how weak and sensitive the local network is under possible nonlinear loads that may be added. This should be taken under consideration despite the limits set by IEC 61 000-3-2 for the current distortion caused by household appliances and similar electrical equipment [1].

TABLE II
NORMALIZED AMPLITUDE (%) OF CFL CURRENT HARMONICS

Harmonic order	20 W	23 W
3	88.9	88.2
5	71.1	69.1
7	48.9	47.4
9	28.9	27.3
11	18.9	18.1
13	16.7	16.1
15	12.6	12.0
17	6.8	6.1
19	2.5	1.7
THD (%)	**130.5**	**127.7**

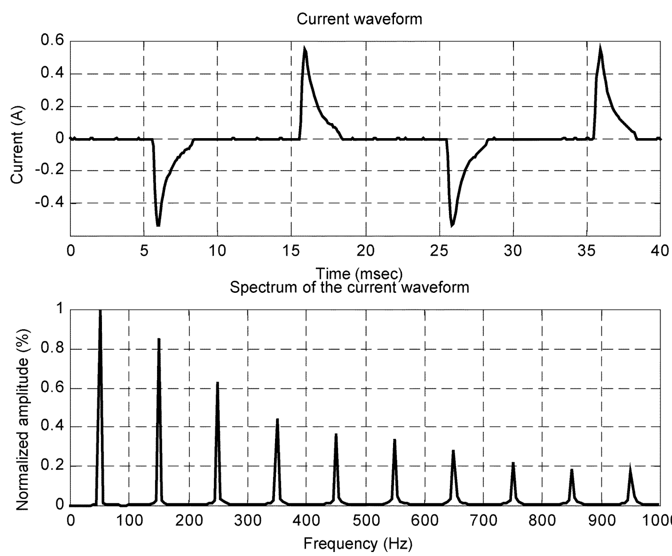

Fig. 3. Measured distorted current of CFLs.

IV. Laboratory Tests on CFLs

In order to obtain real and reliable data concerning the exact current harmonic content of CFLs so that they can be used in the simulation program, many samples of CFLs (Philips, Osram, Sylvania) were tested in the laboratory in order to determine their odd order harmonic spectrum. Such lamps do not produce even-order harmonic currents. The nominal power of the CFLs that are widely used in the households of the island is 20 W and 23 W. It must be also noticed that the phase difference between the supply voltage waveform and the fundamental current waveform of the tested lamps is negligible. However, the power factor is very low (~0.6) due to the considerable harmonic content of current. The measurement of the current harmonics of these CFLs is presented in Table II, while their distorted current waveforms are illustrated in Fig. 3.

All data from the measurements and the energy audit are properly used as input in the simulation model in order to estimate the influence of CFLs to the network voltage distortion.

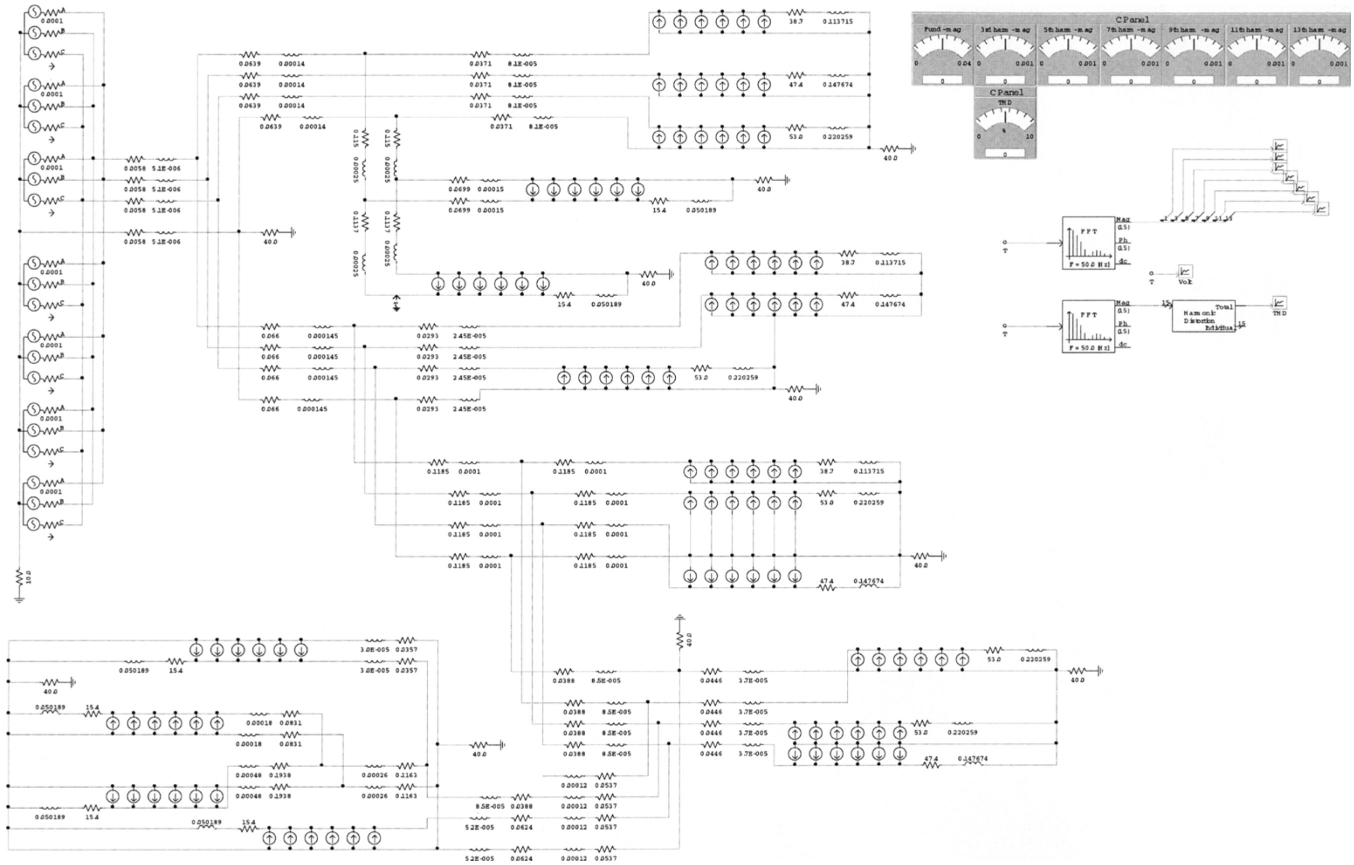

Fig. 4. Simulation of the electric network of the island using current sources to represent the harmonic content of CFLs.

TABLE III
LOAD DEMAND OF TYPICAL RESIDENCES

Load Type	Load characteristics
A	P=200 W; P.F.=0.78; Q=160.5 VAr
B	P=300 W; P.F.=0.85; Q=186.0 VAr
C	P=400 W; P.F.=0.87; Q=227.0 VAr
D	P=900 W; P.F.=0.84; Q=573.0 VAr

V. SIMULATION

All of the electrical characteristics of the network (i.e., distribution lines, load) have to be accurately simulated in order to obtain reliable results. The measured grounding resistance of the inverter was found to be 10 Ω while the average grounding resistance of the tower was 40 Ω. The simulation of the electric network is performed using the PSCAD v3.0.6 software.

All conductors of the electric network shown in Fig. 2 are simulated with their actual lengths, which have been measured in site. The resistance and the inductance are calculated and set as input data according to the type and the cross-section of the conductors.

The inverter is represented by seven discrete three-phase voltage sources. Each source corresponds to the respective harmonic component of the voltage that was measured at the output of the inverter (Table I). The fifth- and the 11th-order harmonics of the inverter output are simulated by sources of negative sequence, the third- and ninth-order components by sources of zero sequence and the 1st and 7th by sources of positive sequence.

According to the energy audit, three typical loads (A: 200 W, B: 300 W, C: 400 W) are considered, as shown in Table III. Some nodes of the real network supply three residences. In that case, the loads of the three residences are added and presented as one (D: 900 W).

The electric network of Arki, after the addition of the harmonic current of CFLs is fully described in Fig. 4.

For the whole island, three load profile scenarios are simulated and examined in this study:

1st scenario: This load profile corresponds to the measured low loading of Table III and sums up to 9-kW total load (30% of the inverter power).

2nd scenario: This load profile corresponds to a possible higher loading of 18 kW total load (60% of the inverter power).

3rd scenario: This load profile corresponds to the maximum loading of the inverter 27 kW (90%).

The observed load-asymmetry between the three phases, according to the energy audit, is taken into account in the simulation of the load in the three-phase network, while the load of every house is reliably assumed to consist of 50% for lighting and 50% for other consuming appliances.

Initially, the electric network was analyzed considering only linear loads, while the THD of the inverter output was considered to be equal to one of the less distorted measured values (3.14%). This is the most favorable network initial condition (almost ideal). In that case the calculation of the THD at all nodes

TABLE IV
IMPEDANCE OF THE LOADS OF TYPICAL RESIDENCES

1st scenario				
	with incandescent lamps		with CFLs	
	R	L	R	L
A	160.9	0.410977	158.5	0.660417
B	127.4	0.251371	142.2	0.443021
C	100.0	0.180701	116.1	0.341145
D	41.8	0.084760	46.1	0.150567

2st scenario				
	with incandescent lamps		with CFLs	
	R	L	R	L
A	80.4	0.205488	79.6	0.330477
B	63.7	0.125685	71.1	0.221510
C	50.0	0.090351	58.1	0.170573
D	20.9	0.042380	23.1	0.075284

3st scenario				
	with incandescent lamps		with CFLs	
	R	L	R	L
A	53.6	0.136992	53.0	0.220259
B	42.5	0.083790	47.4	0.147674
C	33.3	0.060234	38.7	0.113715
D	13.9	0.028253	15.4	0.050189

was found to be 3.14% ±0.09% (Table V) as expected due to the absence of nonlinear loads.

Then, all scenarios examine the variation of voltage harmonic distortion at all network nodes assuming that all incandescent lamps are replaced with CFLs. More specifically, all of the 100-W incandescent lamps are replaced with 23-W CFLs and all of the 75-W incandescent lamps are replaced with 20-W CFLs. In both cases, laboratory measurements showed that the CFLs of 23 W and 20 W have the same maintained luminous flux with the replaced incandescent ones of 100 and 75 W, respectively.

The rest loads are considered to be linear. This consideration is not true but it represents the less distorted load profile of the network. This means that the calculation results will provide the minimum values of harmonic distortion. In fact, the harmonic content will be higher due to the nonlinear behavior of the rest of the loads.

The current harmonics induced by the CFLs of every house are simulated with harmonic current sources of odd order (150 Hz, 250 Hz, etc.) as shown in Table II.

For the purposes of the simulation, the loads of the typical residences of Table III are represented by their equivalent impedance (R and L) as shown in Table IV.

VI. Results and Discussion

The calculation results for all scenarios are given in Table V. The most significant conclusions for all of the examined scenarios are presented and discussed as follows:

1st Scenario: Total Load 9 kW (30%)

- maximum THD_v of line voltage: 10.15%.
- THD_v exceeds the limit of 8% in three out of 42 nodes of the network.
- largest THD_v difference before/after CFLs installation: 6.9% (i.e., the power quality is not affected). This means that in case of a network with ideal source, the voltage THD will never exceed the limit of 8% at any node.
- highest THD_v appears at one terminal node (no. 19), where a large load is connected.

2nd Scenario: Total Load 18 kW (60%)

- maximum THD_v of line voltage: 22.2%.
- THD_v exceeds the limit of 8% at 27 out of 42 nodes of the network.
- largest THD_v difference before/after CFLs installation: 18.9%. This means that even in case of an ideal source, there are nodes of the network with voltage THD $> 8\%$.
- highest THD_v appears at 19 terminal nodes.

3rd Scenario: Total Load 27 kW (90%)

- maximum THD_v of line voltage: 34%.
- THD_v exceeds the limit of 8% at 41 out of 42 nodes of the network.
- largest THD_v difference before/after CFLs installation: 30.8%. This means that even in case of an ideal source, there is a remarkable number of network nodes with $THD_v > 8\%$.
- THD_v exceeds the limit of 8% at all terminal nodes of the network that require special care.

A. Other General Results

The load-asymmetry forces the inverter to work to the extent that the S- and T-connected loads are sufficiently covered, while R absorbs only a small percentage of energy. Most probably, this asymmetry enhances the third and fifth harmonics existence. However, it is certain that the harmonic canceling procedure, which happens at all nodes, is less effective. While designing an autonomous electric network, special care must be given in the equal load distribution on each phase at every node and in total throughout the network.

Given that the rest network loads were considered linear (which is not true), one comes to the conclusion that each time-calculated voltage THD factor is the least possibly expected, when replacing incandescent lamps with CFLs. This also means that even in that ideal case (linearity of the rest of loads), CFLs increase the voltage THD factor near to the acceptable limits of 8% only in the first scenario, because the circulating currents are very low.

The second and third scenarios prove that if the total load of the island is near to the half (60%) or even 90%, then the voltage THD factor is unacceptable at most or all nodes of the network respectively. Accordingly, this means that CFLs installation in that extent (30% and 45% of the islands' installed load) leads to excessive international voltage THD limits.

It is observed that phase S of the 19th node has the largest harmonic distortion in every examined scenario. This node supplies one of the largest loads. Such loads are connected to nodes 18 and 20 on the same phase (load asymmetry). These nodes also appear to have a large voltage THD factor. Such network nodes, defined by the simulation analysis, can be considered as "sensitive nodes" and are suggested for field measurements of the THD_v factor as preselected sites, since they represent—possibly—the worst picture that the harmonic distortion could have throughout the network.

TABLE V
VOLTAGE THD (%) AT ALL ELECTRIC NETWORK NODES FOR THE THREE SCENARIOS

	1st scenario: Total Load 9kW (30%)			2nd scenario: Total Load 18kW (60%)			3rd scenario: Total Load 27kW (90%)		
	Incandescent lamps	CFLs	Difference	Incandescent lamps	CFLs	Difference	Incandescent lamps	CFLs	Difference
Node	THD (%)	THD (%)	%	THD (%)	THD (%)	%	THD (%)	THD (%)	%
1T	3.255	3.980	0.725	3.254	6.119	2.865	3.253	8.850	5.597
1S	3.261	3.400	0.139	3.264	5.274	2.010	3.267	7.936	4.669
1R	3.250	5.742	2.492	3.247	8.053	4.806	3.245	10.780	7.535
2T	3.255	4.020	0.765	3.255	6.207	2.952	3.255	9.009	5.754
2S	3.261	3.432	0.171	3.266	5.383	2.117	3.269	8.109	4.840
2R	3.250	5.776	2.526	3.248	8.117	4.869	3.246	10.880	7.634
3T	3.255	4.372	1.117	3.254	6.863	3.609	3.253	10.020	6.767
3S	3.261	4.397	1.136	3.264	8.142	4.878	3.266	12.480	9.214
3R	3.250	6.553	3.303	3.247	9.472	6.225	3.245	12.920	9.675
4T	3.255	4.630	1.375	3.254	7.728	4.474	3.253	11.910	8.657
4S	3.261	3.449	0.188	3.265	5.496	2.231	3.269	8.306	5.037
4R	3.251	5.860	2.609	3.248	8.287	5.039	3.247	11.130	7.883
5T	3.257	4.622	1.365	3.259	7.191	3.932	3.260	10.530	7.270
5S	3.272	5.285	2.013	3.287	10.420	7.133	3.300	16.030	12.730
5R	3.256	7.110	3.854	3.259	10.510	7.251	3.263	14.500	11.237
6T	3.255	4.391	1.136	3.255	6.919	3.664	3.254	10.110	6.856
6S	3.261	4.422	1.161	3.264	8.175	4.911	3.267	12.540	9.273
6R	3.250	6.570	3.320	3.248	9.505	6.257	3.246	12.970	9.724
7T	3.254	4.709	1.455	3.253	7.896	4.643	3.252	12.150	8.898
7S	3.261	3.463	0.202	3.265	5.571	2.306	3.268	8.432	5.164
7R	3.251	5.909	2.658	3.248	8.385	5.137	3.247	11.280	8.033
8T	3.257	4.706	1.449	3.259	7.260	4.001	3.260	10.650	7.390
8S	3.272	5.939	2.667	3.286	12.040	8.754	3.298	18.500	15.202
8R	3.256	7.444	4.188	3.259	11.100	7.841	3.262	15.410	12.148
9T	3.259	4.755	1.496	3.261	7.429	4.168	3.264	10.890	7.626
9S	3.273	5.345	2.072	3.288	10.550	7.262	3.302	16.220	12.918
9R	3.257	7.232	3.975	3.261	10.720	7.459	3.266	14.820	11.554
10T	3.254	5.667	2.413	3.252	10.190	6.938	3.250	16.580	13.330
11T	3.257	4.706	1.449	3.259	7.260	4.001	3.260	10.650	7.390
11S	3.271	6.844	3.573	3.284	14.240	10.956	3.296	21.870	18.574
11R	3.255	7.801	4.546	3.258	11.770	8.512	3.261	16.450	13.189
12T	3.258	4.752	1.494	3.259	7.298	4.039	3.261	10.710	7.449
12S	3.272	5.965	2.693	3.287	12.090	8.803	3.299	18.580	15.281
12R	3.256	7.485	4.229	3.259	11.180	7.921	3.263	15.530	12.267
13T	3.253	6.205	2.952	3.251	11.320	8.069	3.249	18.970	15.721
14T	3.254	6.038	2.784	3.252	11.080	7.828	3.250	18.020	14.770
15S	3.271	7.513	4.242	3.283	15.830	12.547	3.294	24.310	21.016
16R	3.257	7.979	4.722	3.262	12.100	8.838	3.267	16.980	13.713
17S	3.269	8.875	5.606	3.281	19.120	15.839	3.291	29.360	26.069
18S	3.272	7.612	4.340	3.285	16.050	12.765	3.297	24.660	21.363
19S	3.267	10.150	6.883	3.276	22.190	18.914	3.284	34.070	30.786
20S	3.269	9.383	6.114	3.280	20.290	17.010	3.290	31.150	27.860
Min	**3.250**	**3.400**	**0.139**	**3.247**	**5.274**	**2.010**	**3.245**	**7.936**	**4.669**
Max	**3.273**	**10.150**	**6.883**	**3.288**	**22.190**	**18.914**	**3.302**	**34.070**	**30.786**

The shaded shells represent nodes where the voltage THD exceeds the value of 8%.

Taking into account the above arguments and facts, one can come to the following conclusion: If the voltage THD factor at a "sensitive node" is under the international acceptable limits, then there will be no $\mathrm{THD_v}$ exceed problem throughout the electric network.

The harmonic distortion problem is a complex one, especially in weak low-voltage networks, such as those supplied by autonomous PV stations. In such cases, every significant change of load synthesis to achieve energy savings must be thoroughly studied. Otherwise, problems like unacceptable harmonic distortion will rise. Moreover, it may be not cost effective with such a large-scale load substitution since the cost of giving solution to the created problem is possibly larger than the energy-saving profit itself.

VII. CONCLUSION

The power quality in every weak PV system is very sensitive to nonlinear loads. The use of energy-saving technologies (e.g. CFLs) in order to decrease the power consumption in such networks may result in unacceptable distortions in the network line voltage. Among the main objectives of the energy management team of such networks is to reduce the energy demand and to supply acceptable power quality. It seems that the accomplishment of the first goal opposes the other. An important parameter for energy-saving strategies is the use of CFLs with electronic gear. Measures in that direction must be designed carefully after a thorough investigation of the network. As shown from the simulation, a replacement of incandescent lamps with CFLs of more than 30% leads to unacceptable values of the voltage factor THD (>8%). Depending on the CFLs installation extent, the voltage THD can be increased up to 31%. The problem is enhanced if the existence of other nonlinear loads is also taken into account.

Therefore, in order to achieve and maintain—especially in weak systems—the desired power quality and performance, appropriate directions should be given to the consumers. These should concern the suggested types of electrical equipment (load quality) and the upper limit of their load (load quantity) that will not increase the THD line voltage beyond the limits under which an electric system must operate.

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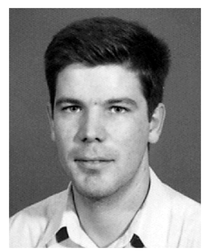

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