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Influence of the photovoltaic generation in a small distribution network

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Abstract. In this paper are presented the results of a study carried out with the data of a electrical energy distribution network in a village in the region of La Rioja (Spain). In this distribution network, property of a small utility, is connected a photovoltaic power plant with a capacity comparable with the total load connected to the network in some hours. In the study there have been used actual load and generation data, discussing the influence of the photovoltaic generation on the net demand of the village over a period of two years (2009-2010). This study is a first phase for the application of demand side management actions for adjusting the load curves with generation curves. In a second phase the influence of new distributed generation facilities, based on renewable sources (wind, biomass, cogeneration, etc.) will be considered in order to minimize the dependence of the village from external supplies.

Key words

Distribution networks, load curves, photovoltaic generation, demand side management.

1. Introduction

This paper presents the results obtained with the analysis of electric power consumptions in the village of Autol. This village, with a population near 5000 inhabitants, is placed in the region of La Rioja, in the north of Spain. The village is fed by an electric distribution network, managed by a small utility (Electra Autol S.A.). A photovoltaic (PV) plant, with a capacity of 2 MW, is connected to the distribution network.

For the study described in the paper, data with load consumption and PV generation values were available on an hourly basis, and they correspond to the years 2009 and 2010.

The study aims to analyze the influence that the photovoltaic generation has had on the global load of the whole distribution network. The results will provide a base scenario for implementing a demand side management (DSM) technique, previously used in other studies [6, 7,8], and with the addition of other generation plants [1,2,3], trying to make self-sufficient all the system covered by that distribution network [4].

The paper is structured as follows: In the second section is described the small power system (the distribution network) under study, as well as the load and generation data, showing the network size and its characteristics. In the third and forth sections are analyzed the data with annual, biennial, and seasonal studies, and the days with special characteristics are also analyzed. The last section presents the conclusions.

2. Distribution network under study

The electrical system under study is a small distribution network that feed loads in the village of Autol (La Rioja). This distribution network belongs and is managed by a small utility, Electra Autol SA. The network is composed by a 15 MVA, 66/13.2 kV power substation (two 7.5 MVA power transformers). This small distribution network is only connected to the power system through the aforementioned power substation.

Several 13.2 kV power lines connect the substation to the low voltage (LV) substations and to the switching substations. High voltage (HV) consumers (13.2 kV) are connected to the network through their own power substations, and low voltage customers are connected through the utility's low voltage power substations.

Table I presents the main technical data of the distribution network under study.

Table I. – Distribution network data.

HV overhead power line (km)	25.458
HV underground power line (km)	16.725
LV overhead power line (km)	33.755
LV underground power line (km)	19.314
Number of LV power substation	37
Installed capacity in LV power substation (KVA)	17515
Number of private customers LV power substations	38
Number of clients	3174
Number of generation plants	1
Installed capacity in power plants (kVA)	2000

With this distribution network, Electra Autol SA is able to meet the load of the village of Autol, with an area of 86.3 km^2 and a population of 4624 inhabitants. The village is placed in the region of La Rioja, in the north of Spain, and the altitude is 458 m.

3. Preliminary results

For this study all the data corresponding to the years 2009 and 2010 were available. The data include hourly records with the consumption of the whole network registered in the HV power substation, as well as hourly generation data of the PV plant. The data were analyzed month by month, calculating the penetration level, which is defined as the percentage, with respect to the total consumption (the load registered in HV power substation plus the power generation), represented by the power generation in the PV plant. The results are shown in Table II.

The electric energy consumed and generated in 2009 were 30902.85 MWh and 4022.94 MWh, respectively. The percentage of the generated energy with respect to the global load was, in 2009, 13.02%. For the year 2010 the electric energy consumed and generated values were 30776.14 MWh and 3798.99 MWh, respectively, with a percentage of 12%.

Figure 1 shows the monthly average penetration level (percentage of the PV generation with respect to the global load) for all the months corresponding to the period of study.

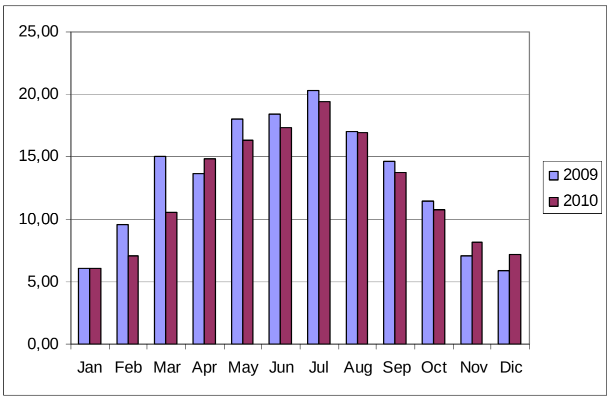

Fig. 1. Penetration level in percentage.

Table II. – Monthly results for the years 2009 and 2010.

	Load (kWh)	Generation (kWh)	Penetration (%)
Jan 2009	**2783681**	168006	6.04
Feb 2009	2430859	231687	9.53
Mar 2009	2551712	384828	15.08
Apr 2009	2396629	327607	13.67
May 2009	2481407	447126	18.02
Jun 2009	2467570	453812	18.39
Jul 2009	2632803	**534115**	**20.29**
Aug 2009	2677444	457124	17.07
Sep 2009	2529064	369595	14.61
Oct 2009	2710500	309701	11.43
Nov 2009	2550904	181582	7.12
Dec 2009	2690277	157757	5.86
Jan 2010	2398689	146510	6.11
Feb 2010	2444364	173222	7.09
Mar 2010	2664667	281571	10.57
Apr 2010	2499710	372112	14.89
May 2010	2465927	402950	16.34
Jun 2010	2361828	409836	17.35
Jul 2010	2623364	508872	19.40
Aug 2010	2610872	441561	16.91
Sep 2010	2580776	355619	13.78
Oct 2010	2759148	296357	10.74
Nov 2010	2593200	210943	8.13
Dec 2010	2773594	199446	7.19

Taking into account the data shown in Table II and Fig. 1, the behaviour of the generation with respect to the global load was similar both years. In the month with greater PV generation, July, the penetration level of PV energy was around 20% of the global load. In the months with lower PV generation, the penetration of this energy to the global demand was around 10%.

4. Data and analysis of consumption and demand

In Fig. 2 and Fig. 3 are shown the maximum hourly average load and maximum hourly average PV generation values for each one of the months in the studied period. As it is shown in Fig. 2, the maximum hourly average load ranges from 5000 to 6300 kWh, while the maximum hourly average PV generation ranges from 1760 to 1830 kWh.

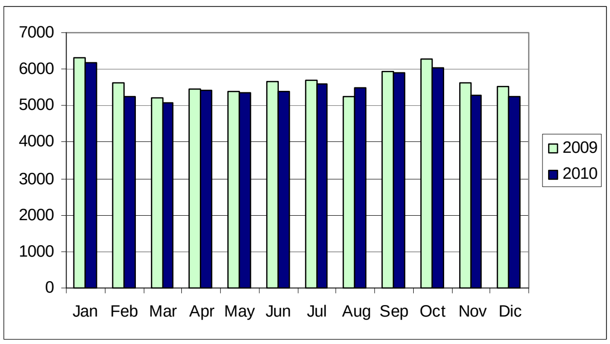

Fig. 2. Maximum hourly average load for each month.

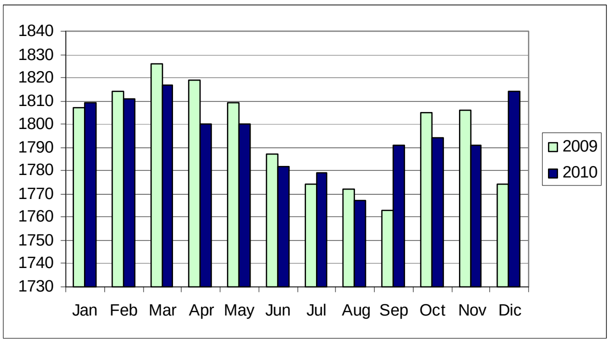

Fig. 3. Maximum hourly average PV generation for each month.

Curiously, the hour with the maximum PV generation value corresponds to spring season, instead summer season, as it could be expected. That hour was the period from 13:00 to 14:00 on March 25, 2009, with a value of 1826 kWh, what represents the 43.1% of the global load, for the whole distribution network, at the same hour. The average temperature was of 15º C for that hour.

In Table III are shown the most relevant results derived from the analysis carried out for each one of the years under study. In that table, h represents the hour of the day, T represents the average temperature at that hour, L represents the load, and G the PV generation. The first row includes the data referred to the hour with the maximum PV generation (March 25, 2009); the second row includes the data corresponding to the day with the maximum load; the third row includes the data corresponding to the day with the minimum load; and the fourth row includes the data corresponding to the day with the maximum penetration level.

Table III. – Most relevant hourly values.

2009					
Date	h	T (ºC)	L (kWh)	G (kWh)	G/L (%)
Mar 25	13-14	15	4238	**1826**	43.1
Jan 7	11-12	2	**6302**	1465	23.25
Jun 21	19-20	21	**1586**	180	11.35
May 3	8-9	13	2582	1762	**68.24**
2010					
Date	h	T (ºC)	L (kWh)	G (kWh)	G/L (%)
Mar 15	13-14	13.6	4499	**1817**	40.39
Jan 27	12-13	3	**6190**	1793	28.97
Jan 23	10-11	6.4	**1222**	82	6.71
Feb 28	9-10	10	2402	1644	**68.44**

The hours with the highest load were from 11:00 to 12:00 on January 7, 2009, and from 12:00 to 13:00 on January 27, 2010. The loads, for both hours, were 6302 and 6190 kWh, respectively. The penetration level values of PV energy in the system were 23.25% and 28.97%. The temperature at those hours was 2 ºC and 3 ºC, respectively.

The highest penetration levels were reached at 8:00 on May 3, 2009, and at 9:00 on February 28, 2010, with 68.24% and 68.44%, respectively.

Notice that the PV generation achieves its best results in hours with average temperature between 10 and 15 ºC, although with temperature values as low as 2 or 3 ºC, the PV generation achieves significant values (1465 kWh, or 1793 kWh, what corresponds to penetration values of 23.25 % and 28.97 %, respectively).

Tables IV and V show the results obtained with a daily analysis. In such tables are presented the maximum and minimum daily average loads for each month. The maximum and minimum penetration levels are also presented.

Table IV. – Results of the daily analysis for 2009.

2009	Daily Maximum			Daily Minimum		
	L (kWh)	G (kWh)	G/L (%)	L (kWh)	G (kWh)	G/L (%)
Jan	102592	11687	17.45	66973	744	0.73
Feb	96698	15245	18.58	68231	1070	1.34
Mar	97809	18218	28.71	61621	2758	2.84
Apr	90506	18155	23.43	59041	2330	3.50
May	92729	21483	33.07	62029	5622	6.62
Jun	99953	21352	34.96	60263	4649	5.23
Jul	100803	21041	30.16	69759	10766	13.36
Aug	99491	18702	26.19	64797	7104	9.56
Sep	99969	16441	24.82	65314	2812	3.48
Oct	105461	15849	25.00	61130	861	0.96
Nov	96180	13315	17.08	65802	1156	1.68
Dec	99295	11674	15.60	66599	678	0.86

Table V. – Results of the daily analysis for 2010.

2010	Daily Maximum			Daily Minimum		
	L (kWh)	G (kWh)	G/L (%)	L (kWh)	G (kWh)	G/L (%)
Jan	97580	11064	14.58	50300	655	0.83
Feb	97914	14408	19.08	64412	998	1.07
Mar	95517	17177	22.00	65417	2089	2.34
Apr	97469	18669	29.57	62193	2875	3.26
May	96302	20801	27.61	58764	3334	4.05
Jun	90746	21424	27.20	58586	3892	5.19
Jul	99761	21138	26.60	66490	6528	7.84
Aug	103777	20069	25.45	65958	4601	5.71
Sep	101421	17703	24.72	69185	2355	2.56
Oct	109341	15240	16.87	66767	1533	1.70
Nov	99181	13675	16.84	68510	379	0.55
Dec	101523	12096	16.47	71933	970	1.00

A set of relevant results can be deduced from the data shown in the tables; these results are referred to the maximum and minimum daily average values. The daily load peak values were between 90 and 110 MWh, achieving the maximum value, for both years, in October (with 105461 and 109341 kWh). The months with the minimum daily peak load values were April, in 2009, and June, in 2010, with values of 90506 and 90746 kWh, respectively.

On the other hand, the minimum daily load values ranged from 50 to 72 MWh, corresponding to January 2010 the day with the minimum daily load (50300 kWh). December 2010 exhibited a peculiar behaviour with all the days with a daily load over 71933 kWh.

With respect to the PV generation, the daily maximum values ranged from 11 to 21.5 MWh. The maximum daily generation values correspond to days in May 2009 and June 2010 (24483 and 24424 kWh, respectively). The worst PV generation values ranged from 379 kWh (December 2010) to 10766 kWh (July 2009). During all the day in July 2009, the PV daily generation value was, at least, 10766 kWh.

The maximum penetration level was 34.95 % (June 21, 2009). The most favourable month was July 2009, with a minimum daily penetration level value of 13.36 %, and a maximum of 30.16 % (in July 2010 the minimum and maximum were 7.84 % and 26.6 %, respectively).

In Figure 4 are plotted the daily average penetration level for all the days of July in both years. July corresponds to the month with greater PV generation values with respect to the load values.

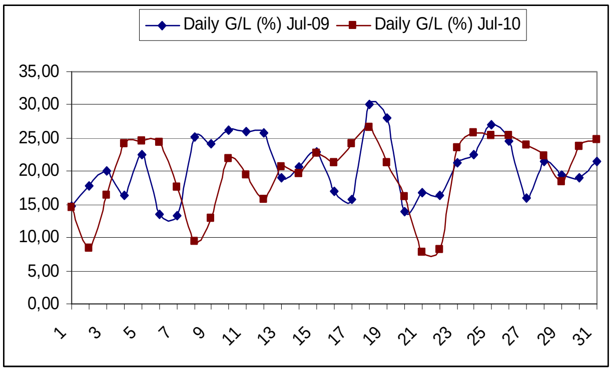

Fig. 4. Daily average penetration level.

Notice that in the month of July, the PV plant fed an important percentage of the load (average values near 20%).

Figure 5 shows the mean daily average load values. As it's shown, the load values were very similar for both years, except for the months of June and March. The mean daily average values range from 77 to 90 MWh. Notice that the maximum load values correspond to the autumn and winter seasons, and the minimum values correspond to spring months.

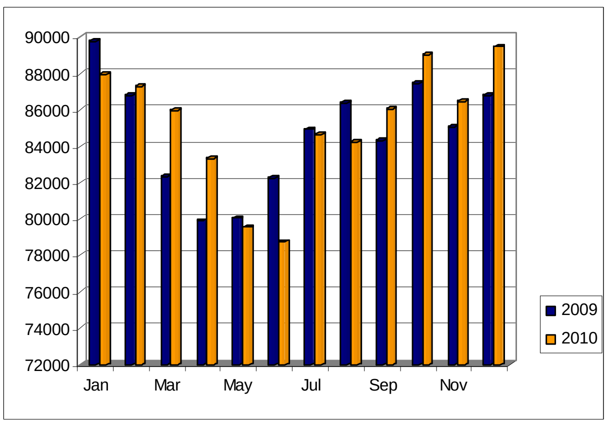

Fig. 5. Mean daily average load values.

Figure 6 shows the mean daily average PV generation values. The values for both years are very similar, showing in the figure a bell shape, with the maximum values in the middle of the year, and, obviously, the minimum values around the end and the beginning of the year.

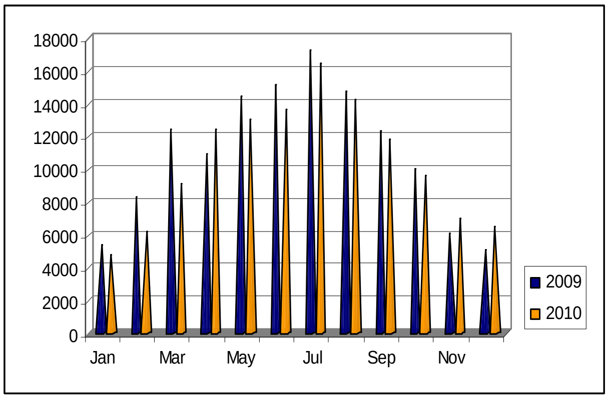

Fig. 6. Mean daily average PV generation values.

If we compare the data plot in figures 5 and 6, the maximum PV generation values coincide with the minimum load values, as a consequence of the greater number of daylight hours in the middle of the year.

Figure 7 shows the mean daily average penetration levels. The shape of the curve for both years is similar to the corresponding to the mean daily average PV generation. The penetration level is greater than 5% for winter months, and greater than 10% for spring and summer months. The maximum mean average penetration level corresponds to the month of July, with level over 20% in both years.

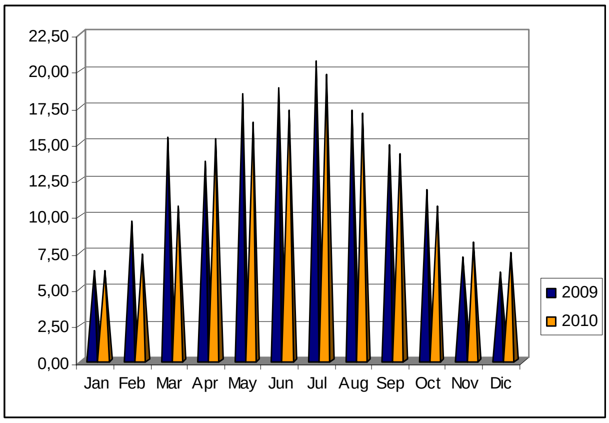

Fig. 7. Mean daily average penetration level.

Tables VI to IX show the data corresponding to days with maximum or minimum temperature values. Table VI includes the data referred to the days (one in each year) with the maximum average temperature, and also includes the average load, PV generation and penetration level values. Table VII includes the data referred to the days with the maximum peak temperatures, and also includes the load, PV generation and penetration level values for the hours corresponding to the maximum temperature. Tables VIII and IX are similar to Tables VI and VII, but including the minimum temperature, instead of the maximum temperature. The hourly average load and PV generation values for the day presented in tables VI to IX are plotted in Figure 8 (maximum temperatures), and in Figure 9 (minimum temperatures).

Table VI. – Maximum average temperature days.

Date	Range T (ºC)	Average T (ºC)	L (kWh)	G (kWh)	G/L (%)
22-07-2009	17 39.4	28.7	96714	15931	16.47
26-08-2010	22.6 41	30.4	103777	12579	12.12

Table VII. – Maximum peak temperature days.

Date	Hour	Max. T (ºC)	L (kWh)	G (kWh)	G/L (%)
22-07-2009	16-17	39.4	4562	1347	30.07
26-08-2010	16-17	41	5196	1104	21.25

Table VIII. – Minimum average temperature days.

Date	Range T (ºC)	Average T (ºC)	L (kWh)	G (kWh)	G/L (%)
18-12-2009	-6.5 4.9	-0.4	96267	3786	3.93
29-11-2010	-6.5 3	-0.2	96502	2250	2.50

Table IX. – Minimum peak temperature days.

Date	Hour	Min. T (ºC)	L (kWh)	G (kWh)	G/L (%)
18-12-2009	2-3	-6.4	2600	0	0
29-11-2010	8-9	-6.5	3934	0	0

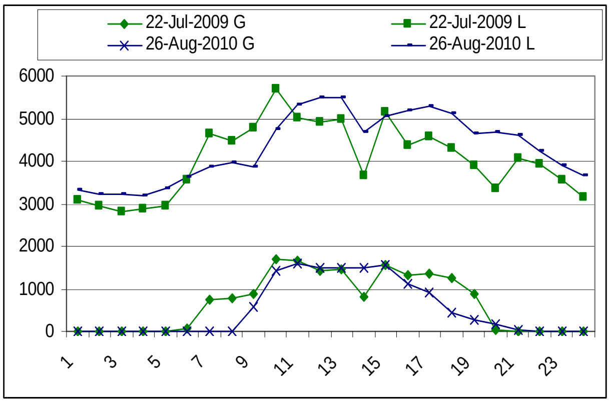

Fig. 8. Hourly average load and PV generation for the days with maximum temperature.

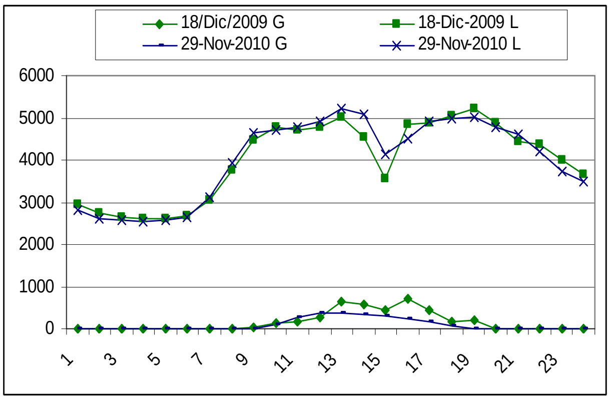

Fig. 9. Hourly average load and PV generation for the days with minimum temperature

Lastly, in Figure 10 are plotted the hourly average load and PV generation values corresponding to the day with the largest average generation in the PV plant (May 31, 2009). For that day the total generation was 21483 kWh, about 33.07 % of the load. The temperature values for that day ranged from 8.5 to 22.5 ºC, with an average value of 14.6 ºC.

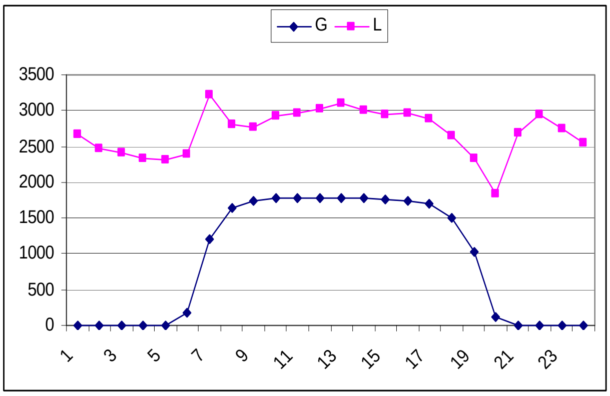

Fig. 10. Hourly average load (L) and PV generation (G) for May 31, 2009.

In the last figure we can observe that the PV plant maintains a regular behaviour for the daylight hours, generating electric energy in a regular manner in the range 1700 to 1800 kWh.

5. Conclusions

In view of the results obtained, we can gather the following:

- The electric load for this small power system (distribution network under study) has a similar behaviour for the two years of the studied period [5]. The PV generation produces energy at peak hours of the electric load and can cover 43% of global load in the best moment, with an average contribution of 20% for all the period.

- Taking into account the similar behaviour of PV generation in both years, and using forecasts of weather variables (temperature, wind speed, solar radiation, etc.), it would be possible to develop a short-term forecasting model for the PV generation.

- Due to the difficulty for storing electric energy to the proper scale, and having as objective to use all the energy generated in PV plant, we propose the application of demand side management actions, as well as the construction of new plants based on other renewable sources that allow to the system to be self-sufficient [1,2,3,4].

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References

[1] Ali Al-Alawi, S.M Islam. "Demand side management for remote area power supply systems incorporating solar irradiance model". Renewable Energy 29 (2004), pp.2027-2036.

[2] Fatih O. Hocaoglu, Omer N. Gerek , Mehmet Kurban. "A novel hybrid (wind–photovoltaic) system sizing procedure". Solar Energy 83 (2009), pp.2019-2028.

[3] Pedro S. Moura, Anibal T. de Almeida. "Multi-objective optimization of a mixed renewable system with demand-side management". Renewable and Sustainable Energy Reviews 14 (2010), pp. 1461-1468.

[4] I.G. Mason, S.C.Page, A.G.Williamson. "A 100% renewable electricity generation system for New Zealand utilising hydro, wind, geothermal and biomass resources". Energy Policy 38 (2010), pp. 3973-3984.

[5] I.J. Ramírez-Rosado, E. Zorzano-Alba, M. Mendoza Villena, P. Lara-Santillán, E. García-Garrido, L. A. Fernández-Jiménez, P. Zorzano-Santamaría, E. Tarancón-Andrés. "Load Management Effects in Electricity Distribution Networks". International Conference on Modelling, Identification and Control, Innsbruck, Austria (2003), pp 246-249.

[6] A. Gabaldon, A. Molina, C. Roldán, J.A. Fuentes, E. Gomez, I.J. Ramírez-Rosado, P. Lara, J.A. Domínguez, E. García, E. Tarancón. "Assessment and Simulation of Demand-Side Management Potential in Urban Power Distribution Networks". IEEE Power Technology Conference (PowerTech), Bologna, Italy (2003).

[7] I.J. Ramírez-Rosado, E. Tarancón-Andrés, "Improvement Of Residential Distribution Systems Operation Via Efficient Electrical. End-Uses Appliances", Proceedings of the 23 rd IASTED International Conference on Modelling, Identification and Control, Switzerland (2004), pp. 402-405.

[8] I.J. Ramírez-Rosado, E. Tarancón-Andrés, "DSM actions and optimal design of residential power distribution systems", Proceedings of the 23 rd IASTED International Conference on Modelling, Identification and Control, Switzerland (2004), pp. 406-410.