Daily Load Profiles for Residential, Commercial and Industrial Low Voltage Consumers

José Antonio Jardini, *Fellow, IEEE*, Carlos M. V. Tahan, M. R. Gouvea, Se Un Ahn, *Member, IEEE*, and F. M. Figueiredo, *Student Member, IEEE*

***Abstract*—This paper presents the results of the study carried out for the determination of the residential, commercial and industrial consumers daily load curves based on field measurements performed by the Utilities of Electric Energy of São Paulo State, Brazil.**

A methodology for the aggregation of these loads to determine the expected loading in equipment or in a preset part of the distribution network by using the representative daily curves of each consumer's activity and the monthly energy consumption of the connected consumers is also presented.

I. Introduction

SÃO PAULO state utilities together with São Paulo University have performed some field measurements to determine consumers' daily load profile behavior, obtaining the representative curves of the most important consumers' classes (residential [1]; commercial and industrial low voltage [2], [3]). A set of distribution transformers load profile was also identified. All the information was stored in a database and is used for planning and engineering studies. They are used for transformer rating selection and management [4], [5], for load diversity evaluation [6] and to determine the expected load profile in any preset point of the distribution network, as examples.

The measurements were performed: in 1992 and 1993 for residential; in 1993 and 1994 for the commercial; and in 1994 and 1995 for the industrial segment.

Places (town and consumers) to carry out measurements were selected to have statistical representativeness.

II. Field Measurements and Methodologies

The measurements of individual consumers load curves were performed in periods of approximately 15 days, using electronic equipment. A sensor (meter) and an electronic device for pulse counting and data storage compose this equipment. The meter is the conventional disc type, where each disc rotation produces an electric pulse. These pulses are counted by the electronic equipment that accumulates them in programmed intervals by the user (1, 5 or 15 min). Thus the average power (demand) at the interval is determined. For the analysis, the curves defined at intervals of 15 min were considered, resulting therefore in 96 points in day curve.

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J. A. Jardini, C. M. V. Tahan, and M. R. Gouvea are with São Paulo University (EPUSP/PEA), S. Paulo, Brazil (e-mail: jardini@pea.usp.br).

S. U. Ahn is with Bandeirante, S. Paulo, Brazil.

F. M. Figueiredo is with CEB, Brasília, Brazil.

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For a certain consumer or transformer, the mean and standard deviation curves, based on measured daily curves values were calculated. These curves are denominated: mean $M(t)$ and standard (std) deviation $S(t)$, where "t" is the interval from 0–24 h in intervals of 15 min. To make load curves compatible to a possible grouping it is necessary to have them on the same basis. A power base P_B was chosen, where P_B is calculated by;

$$P_B = \frac{1}{24}\int M(T)\,dt = \frac{\text{monthly consumption(kWh)}}{24 \times 30}. \quad (1)$$

The curves obtained by dividing the actual curves values by the base power are denominated p.u. curves and nominated as $m(t)$ and $s(t)$. The next step was the determination of the representative curves mj and sj of the various consumers classes. With this aim, residential were grouped by consume ranges. Therefore, the characterization of a residential consumer in a consume range is done by the $m_j(t)$, $s_j(t)$ curves chosen as representatives of the range. For future use, once the monthly consumption (kWh/month) of a certain consumer is known, his daily load curve (M, S) can be obtained by multiplying the values in the representative curve in p.u. of the range to which it belongs by its power base [kWh/(24 × 30)].

A. Residential Consumers

At the beginning, the residential consumers were classified under the following arbitrary consume ranges (kWh/month): from 0–50, from 51–100, and then consecutively in intervals of 50 kWh/month until 300 kWh/month; then intervals of 100 kWh/month from 301–500 kWh/month; then for 501–1000 kWh/month; and more than 1001 kWh/month. For each town the consume frequency distribution in the above-mentioned kWh range was evaluated.

Table I contains the frequency distribution for São Paulo city, the largest location where total average consumption is (220 kWh/month)

The towns were then grouped by kWh frequency distribution similarities. The places to be measured were selected within the following criteria:

- At least one town from all the groups should be chosen.
- The number of consumers in the ranges should be in proportion to the kWh distribution frequency.
- Extreme ranges 0–50 kWh/month and above 501 kWb/month could be disregarded in the first set of measurements.
- Measurements for consumption from 100–300 kWh/month should be a priority.

- Most measurements to be taken in houses, with some check points in blocks of flats.

The definition of the representative curves of a range is not an easy task to be done due to the differences in house loads, (electric appliances) and the dwellers habits rising to curves of different shapes mainly in the peak.

In Brazil the residential customer energy consumption value is mainly due to food preservation (refrigerator, freezer), whilst the shower (water heating) gives the curve peak. The shower uses a resistance device that heats the water when coming out of it. Its power is about 3–5 kW, and the average shower period is 8 min.

Therefore, the characterization of the peak is very hard to be done, for it comprises an analysis of diversity: the own customer diversity, or the diversity among this customer and other customers of the same area.

Relevant to mention that the extreme daily temperature in this region varies from 35°C in summer to 10°C in winter. The energy consumption variation due to weather is less than 10%.

The peak is expected to have also a small variation because, as previously mentioned, it is due to electric shower that has fixed rated power or at most two resistance steps, whose difference in power is about 30%.

No attempt was made in order to evaluate the weather influence because of this aspect. However, measurements were repeated for two consumers both measured in winter and in summer, to get some information for future investigation.

Other points taken in the second step of measurements include also an analysis of the demand average interval, the analysis of power factor profiles, consumption comparison of consumers living in house and in apartment and the behavior of the residential loads in resorts towns.

B. Commercial and Industrial Consumers

Initially a data base was prepared with the information regarding all commercial and industrial consumers connected to LV network. The information collected for each consumer was the name, address, activity classification and the energy consumption for the twelve months of the year, plus the monthly average energy in the same year. Data were first grouped according to the activity and within this activity the consumers were displayed by the descendent order of the monthly average energy. Afterwards the activities were sorted out based on the number of consumers as well as on their total energy consumption.

The results (in part) for the commercial consumers' rank are presented on Table II and industrial consumers on Table III.

The activities ranked from one to twenty were selected for the measurement campaign. The selected subset includes more than 67% of the energy consumption and more than 64% of the number of customers (see Tables IV and V).

C. Measurements Performed

The daily load measurements were performed in many towns in order to include:

- All energy consumption range of residential consumers (from 0–1000 kWh/month).

TABLE I
CONSUMER FREQUENCY DISTRIBUTION

RANGE (kWh)	0 50	51 100	101 150	151 200	201 250	251 300	301 400	401 500	501 1000	1001 above
Freq (%)	10	12	17	18	12	12	11	5	2	1

TABLE II
COMMERCIAL LOADS RANK

		ENERGY		CUSTOMERS	
Commercial Activities	CODE	RANK	MWh	QTY	RANK
Pubs/Canteens	5222	1	24935	44204	1
Restaurants	5221	2	15380	8335	7
Grocery & Bakery	6114	3	14361	14276	4
Bank	5900	4	12317	2606	21
Clothes and Shoes	6112	5	11371	18060	2
Meat and Fish	6113	6	8663	7926	8
Supermarket	6115	7	8134	2309	24
Gas Station	6109	8	5276	2741	20
Surgeries/Vets	5433	9	4652	16140	3
Hotels	5211	10	4419	1846	27
Car Maintenance	5322	11	4218	12023	5

TABLE III
INDUSTRIAL LOW SIZE LOADS RANK

		ENERGY		CUSTOMERS	
Industrial Activities	CODE	RANK	MWh	QTY	RANK
Bakery	2670	1	27854	3471	2
Clothes Factory	2510	2	6460	5562	1
Building Const.	3210	3	2852	2099	4
Lumber Mill/Tank	1160	4	1691	3434	3
Wooden Furniture	1610	5	1465	1614	6
Cement Parts	1060	6	1174	2014	5
Wiring and Loom	2420	7	924	306	18
Var. Wooden Artef.	1550	8	904	979	8
Plastic Gadgets	2350	9	882	228	24
School Mat Printing	2920	10	879	813	9
Electronics	1370	11	874	349	16
Plastic Ind. Purpose	2320	12	821	220	25

TABLE IV
ACTIVITY PARTICIPATION IN THE TOTAL COMMERCIAL (%)

Activities	by MWh/month	by Customers number
1 to 10	50	48
1 to 20	67	64
1 to 30	76	75
1 to 40	82	82
1 to 50	86	88
1 to 60	90	91

TABLE V
ACTIVITY PARTICIPATION IN THE TOTAL INDUSTRIAL LOAD (%)

Activities	by MWh/month	by Customers number
1 to 10	63	58
1 to 20	71	67
1 to 30	79	76
1 to 40	83	80
1 to 50	87	85
1 to 60	90	88

- 47 main commercial activities that are responsible for 85% of commercial energy consumption or 86% of consumers.
- 26 main industrial activities (consumers connected in low voltage), responsible for 76% of the industrial consumption or 71% of consumers.
- Some measurements in distribution transformers and feeders.

Table VI indicates the number of consumers' measurements and the duration of measurements in days, for the various consumers segments.

TABLE VI
ACTIVITY PARTICIPATION IN THE TOTAL INDUSTRIAL LOAD (%)

CONSUMER SEGMENTS/ EQUIPMENT	NUMBER OF CONSUMERS MEASURED	DURATION OF MEASUREMENTS IN DAYS
RESIDENTIAL	158	4018
COMMERCIAL	234	3489
INDUSTRIAL	108	1885
RESIDENTIAL TRANSFORMER	42	2136
COMMERCIAL TRANSFORMER	28	2136

III. REPRESENTATIVE LOAD CURVES

A. Residential

For residential consumers' class, the representative daily curves by utility and by consume range were defined. For each utility, the singular ranges were grouped and were finally: 0–50; 51–200; 201–300; 301–400 kWh/month.

Fig. 1 shows m and s curves for one of these ranges.

The high standard deviation values are due to the diversity in the use of electric appliance mainly the shower.

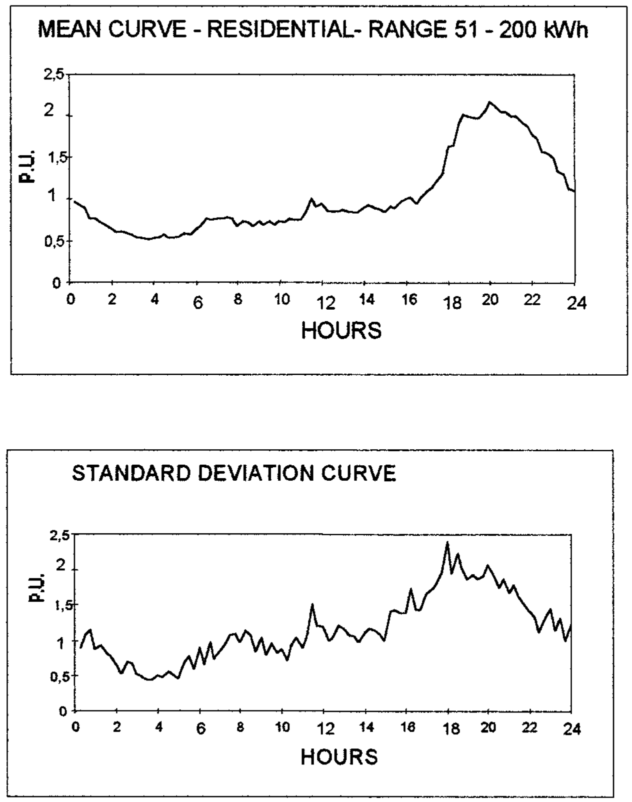

Fig. 1. Residential Consumer Range 51–200 kWh/month—mean and standard deviation curves.

B. Commercial

For the commercial consumers only measurements corresponding to weekdays were considered (Saturday and Sunday were excluded), in the established representative curve. Then the daily load profiles are close to one another, resulting in low standard deviation values.

Fig. 2 shows the curves for one commercial activity.

For most of the commercial activities the deviation curve is low as compared to the mean. With the load curves (m, s) of different consumers in the same activity in hand, one of them was selected to represent the activity (but in certain cases the average of the consumers' curves were selected). Therefore 47 models were established; one for each studied activity In order to have another simple model, group activities with similar load profiles was experimented. This model results in 4 curves shaped as Fig. 3 shows and is recommended for studies that include summarized results.

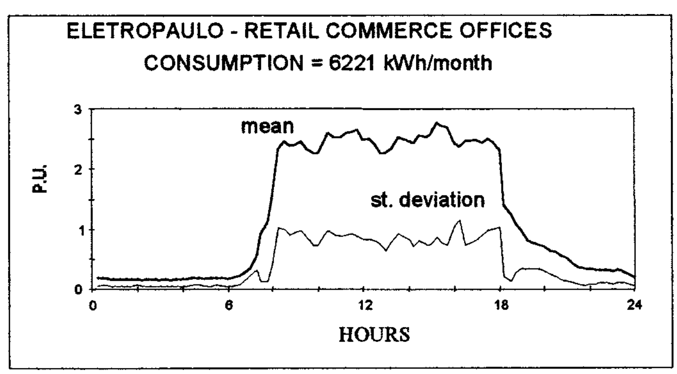

Fig. 2. Representative mean and standard deviation curves of one commercial activity.

C. Industrial

With an approach similar to the one used with the commercial profiles, 26 representatives curves, were establishment, one for each activity studied: an example is shown on Fig. 4.

Concerning the industrial activity standard deviation values found, it is relevant to remember that in most industrial activities there are small size motors with an intermittent mode of operation during the day. Their loads are sometimes high if compared to industries average power, which may lead to quite high values of standard deviation. No attempt was made to derive a simple model for industrial consumer as done for commercial consumer (4 curves type model).

IV. AGGREGATION OF CURVES

Daily load curves in a certain equipment or preset point in the network can be measured to obtain the respective M, S curves (kW-time).

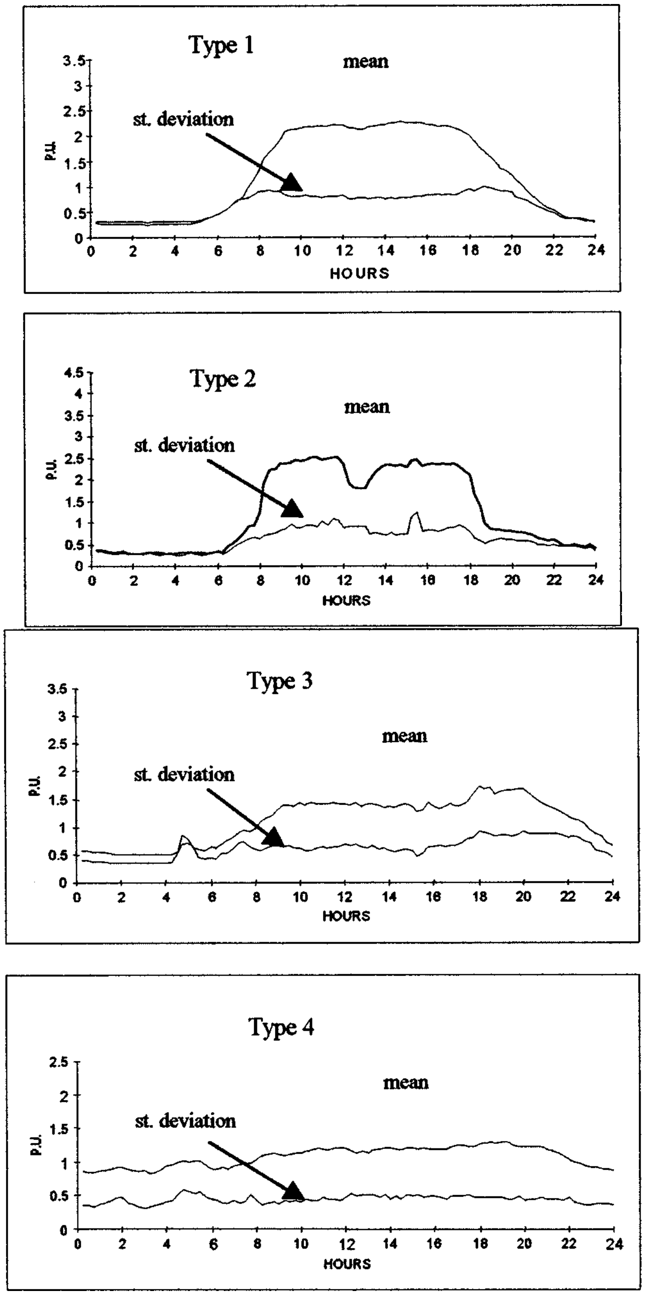

Fig. 3. Groups of consumers' curves.

A daily load curve $F(t)$ with a certain probability of not being exceeded can also be established by assuming a normal distribution of values, applying the expression:

$$F(t) = M(t) + kS(t), \tag{2}$$

where k is the value in a Gaussian distribution table that establishes the probability pr (%), e.g., for $k = 1.3$, pr = 90%; for $k = 2$; pr = 98%.

Apart from measurement directly done in equipment, their mean and standard deviation curves can also be obtained by the aggregation of consumers' curves connected to it.

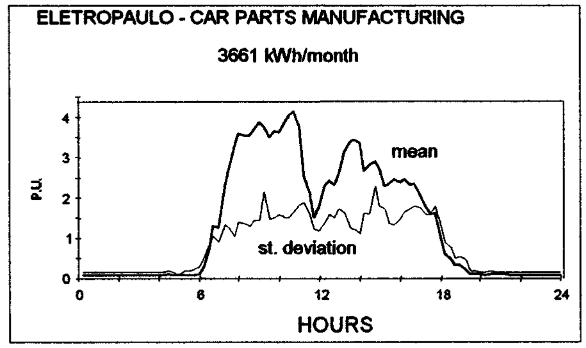

Fig. 4. Representative mean and standard deviation curves of one industrial activity.

Let us suppose for example one transformer with "p" consumers type "a" and "q" consumers type "b." The curves F_i, F_j of each consumer (kW-time) can be expressed by:

$$F_i = m_a P_i + k s_a P_i \tag{3}$$

$$F_j = m_b P_j + k s_b P_j. \tag{4}$$

P_i, P_j are the power base for each consumer.

The aggregation of "p" and "q" consumers will be given by the expressions:

$$M = \sum_{i=l}^{P} m_a P_i + \sum_{j=l}^{q} m_b P_j \Rightarrow M = \sum Mi \tag{5}$$

$$S^2 = \sum_{i=l}^{P} (s_a P_i)^2 + \sum_{j=l}^{q} (s_b P_j)^2 \text{ or } S^2 = \sum S_j^2. \tag{6}$$

Therefore, to obtain M and S curves of an equipment (or preset point of the network) based on the consumers connected to (or ahead) them, it is necessary to:

- Set up a data base with the mean and standard deviation curves in p.u., representative of consumers of the three segments: residential, commercial, and industrial.
- Select the monthly energy consumption of all residential consumers connected to the equipment.
- Select the activity type and monthly energy consumption of commercial and industrial consumers connected to the equipment.

This calculation procedure can be checked by comparing the measurements done in one equipment and by the calculation above described using the data base information.

This comparison was done in the following cases:

1) One transformer that feeds 31 residential consumers, with a total monthly energy of 5040 kWh (Fig. 5).
2) One commercial transformer with 27 consumers units with a total monthly energy of 29 722 kWh (Fig. 6).
3) One transformer with 33 residential consumers and 17 commercial consumers with a total monthly energy of 11 500 kWh (Fig. 7).
4) One feeder that supplies power to 1345 residential consumers, 50 commercial consumers and 6 industrial consumers with a total monthly energy of 412 MWh (Fig. 8).

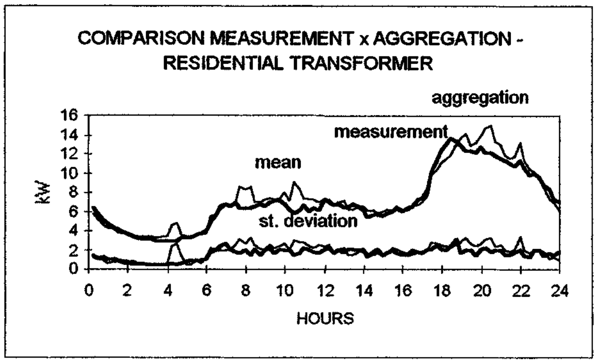

Fig. 5. Measurement and aggregation. Comparison for one residential transformer.

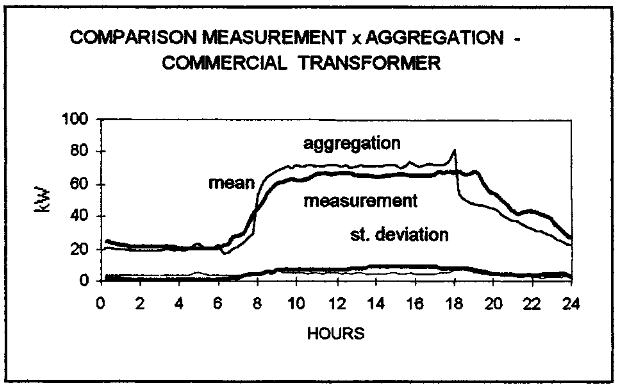

Fig. 6. Measurement and aggregation. Comparison for one commercial transformer.

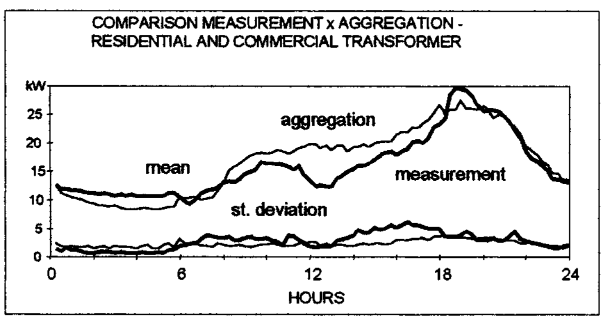

Fig. 7. Measurement and aggregation. Comparison for one residential/commercial transformer.

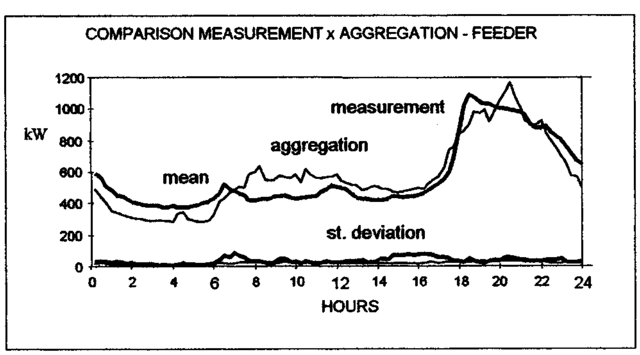

Fig. 8. Measurement and aggregation. Comparison for a feeder.

Figs. 5–8 show that the measured and calculated curves an similar in shape and amplitude (for both the mean and standard deviation curves).

One can conclude that although residential consumers' curves can show high deviations, the aggregation methodology results in small errors. In the transformer, the error is lower than 20% (less than 1 standard deviation) in the peak value in the mean curve.

Therefore, the individual representative curves and the aggregation methodology proposed are considered valid.

V. Use of the Representative Curves

The loading representation of equipment by their mean and standard deviation curves is useful for engineering calculation and statistical analysis. A performance criterion can also be established based on probabilistic values.

The curves in this form have already been used in Brazil for the following applications:

- transformer loss of life calculation;
- secondary distribution system voltage calculation;
- determination of the peak load diversity for residential consumers.

VI. Conclusion

A statistic analysis of residential, commercial and industrial consumers load curves applied to a sample of consumers led to the recommendation of the representative curves of consumers by consume range in the residential and by type of activity in the commercial and industrial sectors.

The consumers' representative curves can be used to obtain daily load curves in any point of the network by aggregation of the consumers' load. The measured and calculated values in various examples validated this procedure.

The paper proposes that customers representative daily load curves are defined statistically form by the mean and standard deviation curves.

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José Antonio Jardini (M'66–SM'78–F'90), was born on March 27, 1941, in São Paulo, Brazil. He graduated in 1963, received the M.Sc. degree in 1971, and the Ph.D. degree in 1973, all at the Polytechnic School of São Paulo University, EPUSP, São Paulo, Brazil. He was employed at Engineering Enterprises, Themag Eng. Ltd., for 25 years where he conducted many power system studies and participated in many important Brazilian projects including Itaipu. He is currently a Professor at EPUSP, teaching power analysis and digital automation and is also a Coordinator at the CED (Center of Excellence in Distribution of Electric Energy), in charge of load model and automation projects.

Carlos M. V. Tahan was born in November 1947 in Minas Gerais, Brazil. He graduated in 1971, received the M.Sc. degree in 1979 and the Ph.D. degree in 1981, all at the Polytechnic School of São Paulo University (EPUSP). He was employed at Engineering Enterprises, Themag Eng. Ltd., with Transmission and Distribution Systems Studies, and participated in important Brazilian projects with hydroelectric power plants such as Ilha Solteira, Tucurui and Itaipu. Since 1989, he has been a Professor at EPUSP and has also been a Researcher at the CED (Center of Excellence in Distribution of Electric Energy).

M. R. Gouvea was born in November 1950 in São Paulo, Brazil. He graduated in 1972, received the M.Sc. degree in 1979 and the Ph.D. degree in 1994, all at the Polytechnic School of São Paulo University (EPUSP). He was employed at Engineering Enterprises, Themag Eng. Ltd., with transmission and distribution systems studies, and participated in important Brazilian projects. Since 1989, he has been a Professor at EPUSP and a Researcher at the CED (Center of Excellence in Distribution of Electric Energy). Currently, he is the Technical Manager of CSPE, an entity encharged for regulations matter and quality of electrical energy supply at São Paulo State, Brazil.

Se Un Ahn was born in 1957 in Inchon, Korea. He graduated in 1981 at Mackenzie University, São Paulo, Brazil. He received the M.Sc. degree in electrical engineering in 1993 and the Ph.D. degree in 1997, both at Polytechnic School of São Paulo University (EPUSP). Since 1986, he has been a Researcher Engineer for Bandeirante (former Eletropaulo) in the Distribution Department, one of São Paulo's utilities, in the field of load forecasting, power delivery, and underground distribution systems.

F. M. Figueiredo was born in 1956 in Ribeirão Preto, Brazil. He graduated in 1978 from Brasilia University, Brasilia, Brazil. He received the M.Sc. degree in electrical engineering in 1994 and the Ph.D. degree in 1997, both at Polytechnic School of São Paulo University (EPUSP). Since 1978, he has been a Planning Engineer for CEB Brasilia Utility. He is also an Associate Researcher at Brasilia University where is teaching distribution engineering.