Voltage quality control at distribution systems applying a fuzzy state estimator

D. G. Colomé and C. E. de la Vega

Abstract-- This work presents a methodological proposal that, through a procedure of fuzzy state estimation, recreates the voltage and demand profile in the distribution system considering uncertainties. The methodology to evaluate the quality proposed here calculates the risk index operation out of the pre-settled voltage limits and quantifies the energy supplied with low quality levels from fuzzy voltage and load levels obtained at each medium/low voltage substation. After the application of the developed methodology to a real case of a radial feeder, those results are compared with the ones obtained by the direct method for quality evaluation through measurements. The methodology requirements show that the proposal has practical application at any distribution system that counts with an appropriate support system to systematize of users and network data.

***Index Terms*— Distribution Systems, quality, voltage level, fuzzy state estimation, pseudo measurements.**

I. INTRODUCTION

THE Great development reached by power systems has had a strong impact, among other aspects, in the increasing level of the supply quality requirements. In this context, those norms imposed by the regulation foreseen the quality control and the application of penalties to the distribution utility which do not fulfill with the pre-settled limits. Penalties having as aim to provide an appropriate economical signal that promotes the necessary investments to improve the quality [1].

A methodological proposal that, through a procedure of fuzzy state estimation recreates the voltage and demand profile considering uncertainties, is presented. Results obtained reflect the uncertainty of pseudo measurements, which together with the few available SCADA measurements; complete the necessary data for the estimation. Pseudo measurements provide load values at each medium/low voltage substation (MV/LV SS), calculated according to typical load curves.

Thus, an algorithm of state estimation based on the weighted least square (WLS) method with branch currents in Cartesian coordinates as state variables is used. The fuzzy state estimation consists of calculating the crisp state estimation using a set of crisp pseudo measurements obtained from central values of pseudo measurements modeled as fuzzy numbers. The state vector obtained is used as linearization point for the propagation of pseudo measurements uncertainty in the state variables and in the remaining estimated electric magnitudes.

The proposed methodology to evaluate quality, calculates the risk index operation out of the pre-settled voltage limits and quantifies the energy supplied with low quality levels from voltage and load levels obtained for each substations of the system by the fuzzy state estimator.

II. PROBLEM STATEMENT AND SOLVING PROPOSAL

Direct methods for quality evaluation consists of recording the voltage profile of a user or set of users, together with the energy consumed at regular periods [1]. Under this scheme it results prohibitive, either due to the associated costs or due to the field work implied, to carry out measurements at great amounts of system points. Thus, all present regulations consider carrying out direct measurements by sampling supported, in the best of cases, on results of previous studies or in users claims. In that way, measurements are restricted to those areas with greater probability of voltage deficit.

A proposal solution integrate measurements with pseudo measurements in a fuzzy state estimation procedure. From the result of the state estimation procedure, voltage and demand values at feeders and LV nodes in MV/LV transformers are generated. Those values modeled with fuzzy numbers consider the uncertainty data and they are used to evaluate the product quality as if they were direct measurements.

A. The fuzzy state estimation model

The state estimation is an algorithm for processing data, that based on a set of measurements and information over topology and network parameters, calculates the state estimated for the system operation [2].

The aim of the state estimation is to determine the most probable state of system for those amounts measured.

This work takes the problem of state estimation in MV feeders of a distribution network.

In order to reach observability in the problem of state estimation of MV network, the few SCADA measurements available on line are complemented with a set of load pseudo measurements in MV/LV SS. Pseudo measurements are not real measurements but they are built with data from the network, users and the weather and even though they comprise a great amount of information to improve the accuracy, pseudo measurements result uncertain. The capacity of the fuzzy logic to solve problems related with uncertainties of information, made convenient and appropriate the application of this technology to model pseudo measurements. When at

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least one measurement is modeled by a fuzzy number the state estimation algorithm that processes it should consider this characteristic.

The fuzzy state estimation (fuzzy SE) methodology at MV feeders carries out a classic calculation of crisp state estimation (crisp SE). Then, it spreads the uncertainty of pseudo measurements to state variables [3]. Finally, it determines the estimated electric magnitudes modeled with fuzzy numbers.

i.) Crisp state estimation in MV feeders

The crisp state estimation model developed is apt to estimate the state of the radial feeder with eventual loop formation together with MV/LV transformers. Through tests carried out, this model has proved to provide satisfactory results.

The WLS method proposed based in branch currents [4], is adopted for the crisp state estimation of the MV feeder. This is reformulated for an single line simplified and balanced network model and for a decoupled structure that reduces effort and calculation time. This algorithm is especially apt for radial or weekly meshed feeders, where the real I_r and imaginary I_x currents components in all feeder branches are defined as state variables (1).

$$x^T = [I_{r1}\, I_{r2} \ldots I_{rM}\; I_{x1}\, I_{x2} \ldots I_{xM}] \tag{1}$$

a) Weighted least squares method;

The WLS method is the most used technique in the state estimation [2]. This is an iterative method that processes a set of redundant measurements. The mathematical model that relates these measurements with the state variables is given by:

$$Z = h(x) + v \tag{2}$$

This is an optimization problem where the objective function to be minimized is the sum of weighted square residues and it is given by:

$$J = \sum w_i (Z_i - h_i(x))^2 \tag{3}$$

Where

Z_i : Measurement value
x:State variable
$h_i(x)$: Measurement function
w_i: Measurement weight
v: Measurement error

Residues are calculated as the difference between the estimated results and measurements, their weight in the objective function depend on the accuracy of measurements. Measurement errors belong to a N(0, σ_i^2) distribution, the $w_i = 1/\sigma_i^2$ weight factor indicates that the most accurate measurements have greater weight in the estimation.

b) Measurements model h(x)

In this formulation, measurements are expressed according components of branch currents. Nodal injection measurements (P_i, Q_i) are represented as an injection current through currents balance of (4), expressed according to state variables, where *Mie* and *Mis* are branches connected to node *i.* Flow measurements (P_{ij}, Q_{ij}) at branch *l* are represented as a branch current directly with the state variables associated to the *l* branch, according to (5).

For the formulation of current module measurements I_{ij} at branch *ij*, the lineal function of (6) was adopted [5], which leads to a decoupled formulation while the gain matrix remain constant.

$$P_i + jQ_i = \sum_{l=1}^{Mie} (I_{rl} + jI_{xl}) - \sum_{l=1}^{Mis} (I_{rl} + jI_{xl}) \tag{4}$$

$$P_{ij} + jQ_{ij} = I_{rl} + jI_{xl} \tag{5}$$

$$I_{ij} = I_{rl} + jI_{xl} \tag{6}$$

The function of voltage measurements V_i assumes that the power injection (P_i+jQ_i) is also measured in the node. A lineal function of the measurement is achieved with (7), where the injection current is expressed according to state variables using (4).

$$\frac{1}{V} = \frac{I_{r_{iny}} - jI_{x_{iny}}}{P_i + jQ_i} \tag{7}$$

c) Equivalent measurements

The iterative process of the WLS method requires the calculation at each *k* iteration of the residual vector. When the measurement functions *h(x)* are expressed as current measurements it is also necessary to convert *z* measurements in equivalent currents measurements z_{eq}. Injection and flow equivalent measurements are obtained with (8), with voltage V_i in the injection node or in the node of the branch where the flow is measured.

$$z_{eq}^k = \left(\frac{z}{V_i^k} \right)^* \tag{8}$$

Equivalent current and voltage measurements are calculated including phase information with E (9) and (10).

$$z_{eq}^k = z \frac{I_l^k}{\left| I_l^k \right|} \tag{9}$$

$$z_{eq}^k = z \frac{\left| V_i^k \right|}{V_i^k} \tag{10}$$

Equivalent measurements are updated with I^k branch currents and V^k nodal voltages calculated at each iteration *k*. Applying the WLS method, the I^k is calculated and from it V^k can be obtained using (11).

$$V_i = V_f - \sum_{l=1}^{Mir} (I_{rl} + jI_{xl}) \cdot z_l \tag{11}$$

d) Treatment of measurements and pseudo measurements

Generally, the only on line measurements available in feeders, are those at the start of feeder (voltage and current magnitude, and active and reactive power flow). Some systems also count with measurements for monitoring the technical product quality and the performance of automatic equipments, as voltage regulators. These measurements grouped in $h_1(x)$, together with zero injection at passive nodes [6], grouped in $c(x)$, are the only measurements with information over the real operation state. Therefore, they are considered as accurate measurements and they are modelled as equality constraints using the augmented matrix approach and the Lagragian method [2], [6].

Uncertain load pseudo measurements modelled with fuzzy numbers, at the crisp state estimation, are defuzzified using their central value. These crisp pseudo measurements are modelled with measurement errors belong to a $N(0,\sigma^2)$, as it is required by the WLS method [2] and grouped in $h(x)$.

e) Decoupled formulation of the WLS state estimation

The WLS state estimation based on branch currents leads to a decoupled formulation with two problems: one that includes the real components of the measurement function h_r, and the real component of branch currents I_r and the other, that includes the imaginary components of functions h_x and branch currents I_x [5].

The decoupling between the real and imaginary problem is achieved without carrying out simplifications or considerations respect line parameters, at all measurement functions except in voltage measurements.

The decoupled WLS algorithm with equality constraints based on branch currents involves the iterative solution of (12).

$$\left[\begin{array}{ccc|ccc} G_{rr} & C_r^T & H_{1r}^T & 0 & 0 & 0 \\ C_r & 0 & 0 & 0 & 0 & 0 \\ H_{1r} & 0 & R_{1r} & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & G_{xx} & C_x^T & H_{1x}^T \\ 0 & 0 & 0 & C_x & 0 & 0 \\ 0 & 0 & 0 & H_{1x} & 0 & R_{1x} \end{array}\right] \left[\begin{array}{c} \Delta I_r^k \\ \lambda_r^k \\ \mu_r^k \\ \hline \Delta I_x^k \\ \lambda_x^k \\ \mu_x^k \end{array}\right] = \left[\begin{array}{c} H_{rr}^T W_r \Delta z_r^k \\ -c_r(I_r^k) \\ z_{eq_{1r}} - h_{1r}(x^k) \\ \hline H_{xx}^T W_x \Delta z_x^k \\ -c_x(I_x^k) \\ z_{eq_{1x}} - h_{1x}(x^k) \end{array}\right] \quad (12)$$

The iterative solution of the algorithm for the crisp SE includes the following steps:

1. Initialize the state vector x^0.
2. Calculate of initial equivalent measurements z_{eq}^0
3. Calculate of measurement functions $h(x)$, $h_1(x)$ and $c(x)$
4. Building the measurement Jacobian H, C and H_1.and covariance matrices R and R_1.
5. Calculate the gain matrix G
6. Decouple the matrices in blocks of real and imaginary components.
7. Formation of augmented gain matrices G_{rrEC} and G_{xxEC} of (12).
8. Starts iteration k=0
9. Calculate the residues for each type of measurement.
10. Calculate the right hand side of (12)
11. Solve (12).
12. Update $x^{k+1}=x^k+\Delta x^k$ or I^{k+1}, V^{k+1} and z_{eq}^{k+1}
13. Test of convergence, if no go to step 9. Else stop.

This algorithm does not require that measurements Jacobian and gain matrices are updated at each iteration.

- *Propagation of uncertainties at the estimated state*

Once the crisp SE is carried out the following step in the fuzzy SE is to affect the estimated state variables with the uncertainty of pseudo measurements. The crisp estimated state vector x_c is used as linearization point to calculate, with (13), fuzzy variations present in fuzzy pseudo measurements. Then, these fuzzy variation are spread to state variables using (14). Finally, knowing the crisp state vector and fuzzy variations it is possible to calculate the fuzzy state vector with (15).

$$\Delta \tilde{z} = \tilde{z} - h_f(x_c) \quad (13)$$

$$\Delta \tilde{x} = \left(G_f^{-1} H_f^T R_f^{-1}\right) \Delta \tilde{z} \quad (14)$$

$$\tilde{x} = x_c + \Delta \tilde{x} \quad (15)$$

In the decoupled formulation based on branch currents, Jacobian H_f and gain matrix G_f result constant and do not depend on x_c.

Uncertainties propagation in state variables includes the following steps:

1. Building the hf function with load pseudo measurements together with zero injections.
2. Uncertainties propagation with E (16) and (17).

$$\Delta \tilde{I}_r = H_{frr}^{-1} \Delta \tilde{z}_{eq_r} \quad (16)$$

$$\Delta \tilde{I}_x = H_{fxx}^{-1} \Delta \tilde{z}_{eq_x} \quad (17)$$

3. Building the hf function with pseudo measurements, SCADA measurements and zero injections.
4. Uncertainties propagation with (14),
5. Control of state variables uncertainty calculated at steps 2 and 4,
6. Calculation of fuzzy state vector with (15).

The uncertainties control consists of reducing fuzzy variations determined only with pseudo measurements, step 2, to the fuzzy variations that result of including SCADA measurements, step 5. In this way, SCADA measurements reduce the uncertainty of state variables in which they have influence. The most clear case is that of the current in the initial branch of the feeder where the injection measurement in the start of feeder reduces the uncertainty practically to zero.

- *Determination of estimated fuzzy magnitudes*

With the aim of calculating fuzzy power magnitudes (flows and injections) the non linear functions $f(x)$ are formed to express electrical magnitudes to be estimated in terms of the state variables [3]. Functions $f(x)$ are linealized around the central value of the fuzzy state vector:

$$\Delta \tilde{f} = \left.\frac{\partial f}{\partial x_1}\right|_{x_c} \Delta \tilde{x}_1 + \left.\frac{\partial f}{\partial x_2}\right|_{x_c} \Delta \tilde{x}_2 + \ldots + \left.\frac{\partial f}{\partial x_n}\right|_{x_c} \Delta \tilde{x}_n \quad 8.a)$$

which in matricial form

$$\Delta \tilde{f} = F\ \Delta \tilde{x} \quad (18.b)$$

with F Jacobian matrix of $f(x)$ that is constant and do not depend on x_c. Fuzzy wideness of state variables are expressed according to (14), and it results

$$\Delta\tilde{f} = F\ (G^{-1}H^T R^{-1})\Delta\tilde{z} \qquad (19)$$

The final membership function is obtained adding the fuzzy amounts to the value calculated with the crisp SE with (20).

$$\tilde{f} = f(x_c) + \Delta\tilde{f} \qquad (20)$$

Fuzzy variations of nodal voltages were not calculated with (19) since in the decoupled formulation simplifications should be carried out that would only lead to the approximate calculation of estimated fuzzy voltages.

With the aim of calculating nodal voltages estimated fuzzy (21) is applied where *Mir* is the set of branches covered from the source node to the *i* node.

$$\tilde{V}_i = V_f - \sum_{l=1}^{Mir}\left(\tilde{I}_{rl} + j\tilde{I}_{xl}\right)\cdot z_l \qquad (21)$$

As result, voltage and load levels estimated for each substation of the system are obtained, characterized by fuzzy numbers that reflect not only the certain information of SCADA measurements but also the uncertainty of load pseudo measurements.

A. Generation of fuzzy load pseudo measurements

Due to the low availability of measurements, a methodology has been defined to generate pseudo measurements representative of active and reactive power loads at each MV/LV SS [7],]8]. With pseudo measurements feeders are observable in the state estimation problem.

It is applied a procedure to model the load that comprises data from different information systems of the distribution utility: Typical load curves determined from tariffs studies, data of users consumption of invoice files from the Customer Information System, geographical information of users connectivity from AM/FM GIS, and measurements of weather states carried out on line.

Based on the typical load curve and the energy consumption, the demand of the different users is estimated. Those values obtained together with typical loss values are added to obtain an estimated value of nodal demand.

In order to achieve a pseudo measurement that fits as close as possible to the real operation state, load curves are classified by sector and by consumption band, season of the year, type of day in the week and by the hour of the day. In the de-normalization of the curve with the energy consumption corresponding to the same month of the previous year, the demand grow index and that not all days of the week have the same consumption are taken into account.

The proposed methodology carries out the application of artificial neuronal networks (ANN) to adapt pseudo measurements to the weather state. The load non lineal behaviour with the temperature and with other representative variables of the weather state is appropriately modelled with ANN [9].

In order to include the real time load behaviour, the proposed methodology carries out the adaptation of pseudo measurements P_i to SCADA measurements P_{cab} in the start of feeder taking into account losses in the feeder P_{perd}, (22).

$$P_{i\,adap} = (P_{cab} - P_{perd})\frac{P_i}{\sum_{i=2}^{N} P_i} \qquad (22)$$

Load pseudo measurements are not represented with a unique value, but with a mean and a standard deviation, Fig. 1, from which it is possible to determine with a certain level of confidence a range of possible values for the pseudo measurement.

This range of possible values of pseudo measurements is translated, applying the possibility-probability consistency principle [10], into a fuzzy number with a trapezoidal possibility distribution by assigning a degree of membership between 0 and 1 to each possible value of the load.

For a pseudo measurement with average value P_i and standard deviation $\sigma i P_i$, a function of trapezoidal membership with breakpoints of (23), with a=0.5 [10] and b=4.5 is adopted.

$$\tilde{P}_i = [P_i - ab\sigma_i P_i \quad P_i - a\sigma_i P_i \quad P_i + a\sigma_i P_i \quad P_i + ab\sigma_i P_i] \qquad (23)$$

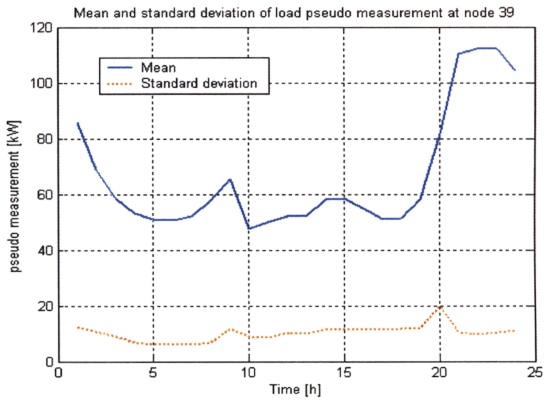

Fig. 1 Mean and standard deviation of active load pseudo measurement at each hour of a day.

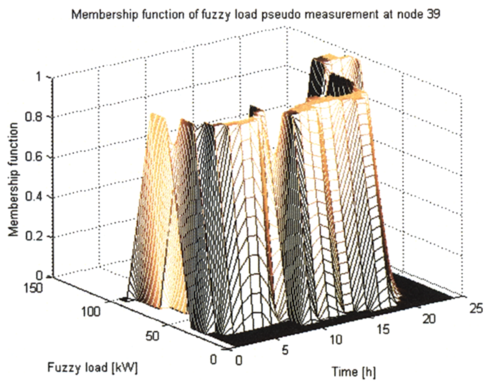

Fig. 2 Membership function of the pseudo measurement of Fig. 1.

The membership function assigned to the active load pseudo measurement of Fig. 1 is represented in Fig. 2.

B. Proposed methodology

From the result of the estimation, voltage and demand estimated values are obtained at each LV node of the MV/LV SS, to which are connected users. Fuzzy values of voltage are used to evaluate the quality of the product through the calculation of the risk index operation out of the pre-settled voltage limits (RIOVL) and the demands estimated to determine the energy supplied without enough quality. The index is calculated comparing the estimated fuzzy voltage with the limit of voltage imposed by the quality requirements. The index RIOVL is defined as the maximum membership value among values of membership associated to the magnitude voltage value out of the pre-settled limits, according to (24) for the maximum voltage limit V_{max} and with (25) for the minimum voltage limit V_{min}.

$$RIOVL = \max\left(\mu_{\tilde{V}_i}(V_i) \quad : \quad V_i > V_{\max}\right) \tag{24}$$

$$RIOVL = \max\left(\mu_{\tilde{V}_i}(V_i) \quad : \quad V_i < V_{\min}\right) \tag{25}$$

Estimated fuzzy magnitudes and pseudo measurements are modelled with fuzzy trapezoidal numbers. In Fig. 3 are included fuzzy voltage magnitudes at LV nodes of MV/LV SS and the minimum voltage limit at 0.93 pu. In Fig. 3.a the RIOVL is 0.65, in fig. 3.b it is 1 and in fig 3.c zero, because it is operating within limits.

The energy supplied without enough quality EQL_i in the MV/LV SS is calculated considering the energy of each period in which the RIOVL is different to zero, with (26), the energy of the period k is affected by the RIOVL index calculated for the MV/LV SS i.

To determine EQL_i, different breakpoints of fuzzy load $\tilde{P}_{ik}$ and the period of time Δt are used. The result is an energy magnitude EQL_i modelled with a fuzzy number.

$$EQL_i = \sum_{k=1}^{T} \tilde{P}_{ik}\ RIOVL_{ik}\ \Delta t \tag{26}$$

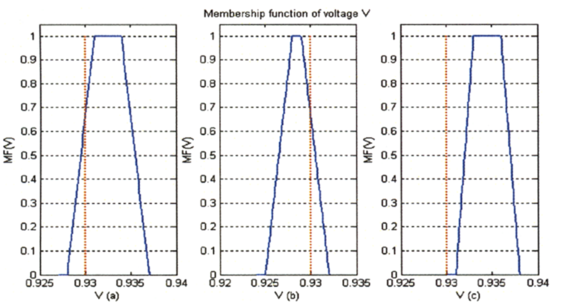

Fig. 3 Fuzzy voltage at the LV output of a MV/LV SS

III. APPLICATIONS

In order to analyze the behaviour of the proposed methodology it has been applied to a real feeder corresponding to the distribution system of San Juan province, Argentina. The proposal feasibility was analyzed as regards calculation and consistency of results. Besides, the results were compared with those obtained with the application of the direct method for quality evaluation based on measurements.

The norm that establishes to carry out quality voltage level measurements at the LV side of the MV/LV SS was used as quality norm. The voltage and current or active power at the output of the distribution transformer are measured so as to include all users supplied by the MV/LV SS. The norm settles that according to voltage records and bands that may be penalized or not foreseen by the norm, the penalization is applied to the recorded active power. The resulting amount is returned to all customers as discount due to the low quality product, proportionally to the consumption level of each user at the same period. In the application of the methodology proposed, the fuzzy state estimation is carried out obtaining, at the LV side of MV/LV SS, the voltage profile and the estimated load modelled with fuzzy numbers. From the estimated voltage profile and having into account bands that may be penalized, the index RIOVL is calculated with (24) and (25) and the energy supplied without enough quality at each MV/LV SS with (26).

The scheme of the analyzed feeder is shown in Fig. 4. It is a radial feeder in 13.2 kV with 39 nodes and 38 branches, 21 nodes of pseudo measured loads, with a maximum load of 274 kW and 150KVAr. There are shunt capacitors for reactive compensation at node 38. The feeder has nodes connected to very short and long lines, simultaneously.

Three cases are analyzed, all of them with voltage magnitude and active and reactive power measurements in the start node of the feeder and with pseudo measurements of fuzzy load in MV/LV SS during a period of 24 hours. These cases are different according to the level of reactive compensation and by the tap position in MV/LV transformers.

Case 1: 100 kVAr and tap in nominal position.
Case 2: 300 kVAr and tap in nominal position.
Case 3: 300 kVAr and tap in a position different to the nominal one.

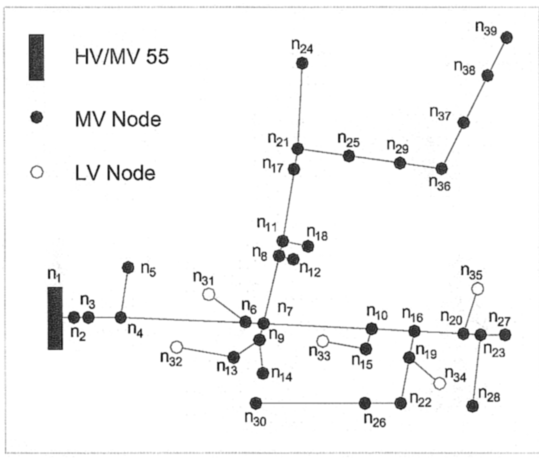

Fig. 4. 39 nodes feeder

The voltage and load estimated fuzzy profiles at node 39 in MV corresponding to case 1 are included in Fig. 5. Load and voltage at nodes 39 and 31 in LV for case 2 are shown in Fig.

6 and Fig 7. Those corresponding to node 31 in case 3 are represented in Fig. 8. The real value of these magnitudes, obtained by simulation with a load flow calculation is also included in Fig. 5 to 8.

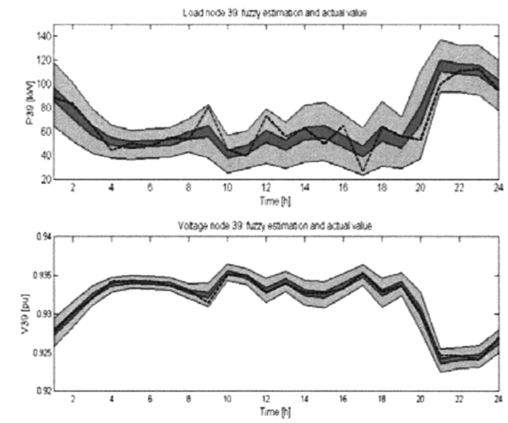

Fig. 5. Estimated fuzzy and real profile at node 39, case 1.

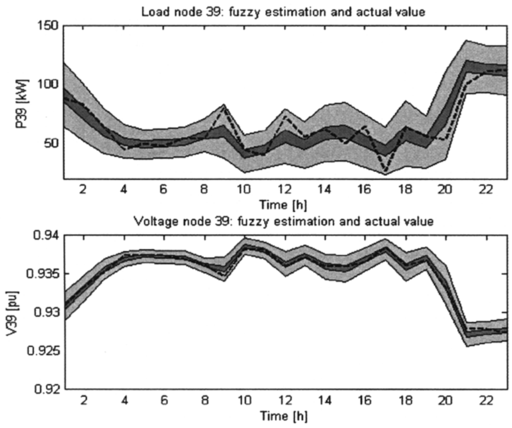

Fig. 6. Estimated fuzzy and real profile at node 39, case 2.

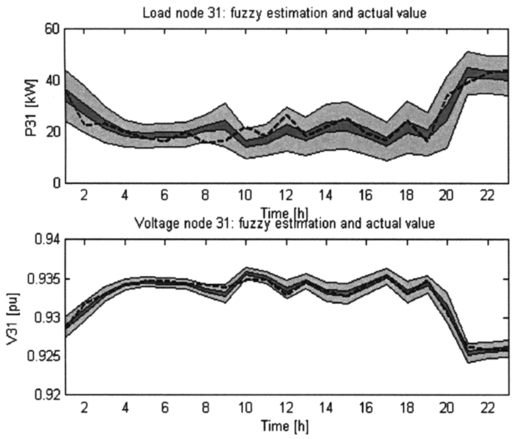

Fig. 7. Estimated fuzzy and real profile at node 31 in LV, case 2.

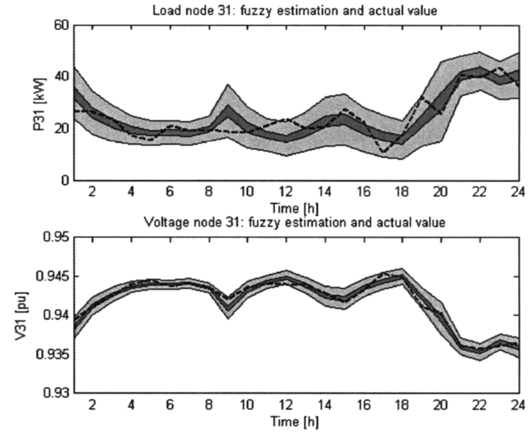

Fig. 8. Estimated fuzzy and real profile at node 31, case 3.

The estimated fuzzy voltages profile for an hour near to the peak at all feeder nodes in cases 1 and 2 are shown in Fig. 9. Comparing Fig. 5 and Fig 6 and analyzing Fig. 9 it is observed that through the increase of the reactive compensation in the feeder the voltage profile improves mainly at all nodes connected to the same branch of shunt capacitors.

Comparing Fig. 7 and Fig 8 it is observed that the modification in the tap position of the MV/LV transformer that supplies the load of 31 node produces great improvements in the LV voltage profile.

Fuzzy energy values supplied with deficient quality at nodes 31 and 39 during the 24 hours analyzed are put forward in Table I. They are compared with the energy that would be determined applying the direct method based on measurements, which it is included in the range of possible values calculated with the fuzzy methodology proposed.

It can be said that those fuzzy results obtained provide an information that reflects the uncertainty of pseudo measurements and at the same time they include those results that would be obtained by applying the direct method based on measurements, whose implementation is not economically feasible.

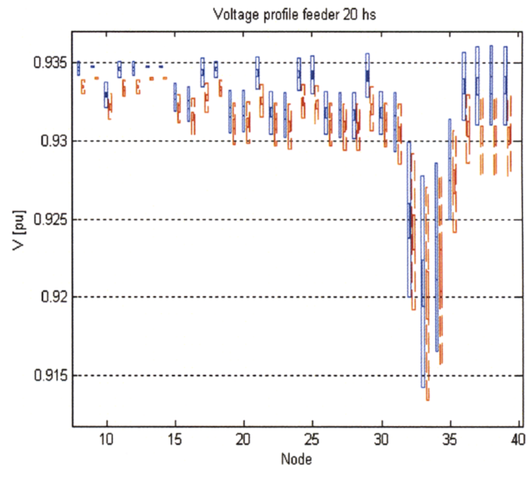

Fig.9 Estimated fuzzy voltage profile in the feeder, cases 1 (dashed line) and 2 (full line).

TABLE I
ENERGY SUPPLIED WITH DEFICIENT QUALITY, RESULTS WITH FUZZY EE AND DIRECT METHOD.

Node	Energy supplied with deficient voltage quality				
	Direct Method	Calculation with EE fuzzy results			
	[kWh]	ECI(1) [kWh]	ECI(2) [kWh]	ECI(3) [kWh]	ECI(4) [kWh]
Case 1					
Node 39	559.0	852.2	717.98	641.27	507.0
Node 31	229.9	317.3	267.3	238.7	188.69
Case 2					
Node 39	506.36	602.1	522.3	476.7	396.9
Node 31	195.84	274.8	234.3	211.2	170.5
Case 3					
Node 39	507.3	605.9	523.0	475.7	392.8
Node 31	0	0	0	0	0

IV. Conclusions

The methodology proposed allows to replace the requirement of direct measurement in field of voltage and power profile by a calculation of fuzzy state estimation to evaluate the quality. Results show that the application of the fuzzy state estimation to valuate the quality and determine the energy supplied with an insufficient quality of voltage level results appropriate even more when it reflects the own uncertainty of estimated loads.

The applied algorithm of state estimation, due to its resources and calculation time requirements, results specially appropriate in the estimation of large scale radial electric networks as distribution systems.

An index which expresses the risk of operating out of the voltage limits has been defined. This index considers the uncertainty in loads and it is calculated analyzing fuzzy numbers which model voltage and load estimated magnitudes. From that sub or over voltage risk index it is possible to carry out a valuation of the quality of the product at the level of each MV/LV substations and to translate it to a quantification of the energy supplied with deficient quality.

This methodology also allows to define manoeuvres or actions in the feeder that lead to improve the voltage profile and therefore the product quality.

This work show that the application of the state estimation to the problem of supervising and controlling voltage levels results an interesting proposal, even more nowadays that distributing enterprises count with technical means for implementing it.

V. References

[1] Furlan N.L., Colomé D.G., Mut O., Pringles R., Andreoni A., Determinación de la calidad real del nivel de tensión de un sistema de distribución utilizando un estimador de estado. CIDEL Argentina 2006, Bs.As, nov. 2006.

[2] Ali Abur and A. Gómez Expósito: Power system state estimation. Theory and implementation, Marcel Dekker Inc., 2004.

[3] V. Miranda, J. Pereira and J. Tomé Saraiva: State estimation in DMS- combinig Fuzzy information and measurements; CIRED Argentina'96, BsAs (2-5 Dec 1996), Session 3 pp 147-152.

[4] M.E. Baran and A. Kelley: A branch-current-based state estimation method for distribution systems; IEEE Trans. on Power Systems Vol 10 N° 1 (Feb 1995), pp 483-491.

[5] W-M Lin, J.H. Teng and S-J Chen: A Highly efficient algorithm in treating current measurements for the branch-current-based distribution state estimation, IEEE Trans on Power Delivery Vol 16 N° 3 (July 2001), pp 433-439.

[6] W.-M Lin and J.-H Teng: State estimation for distribution systems with zero-injection constraints; IEEE Trans. on Power Systems Vol 11 N° 1, Feb. 1996, pp 518-524.

[7] R. M. Pringles y D.G. Colomé: Pseudo-mediciones de carga en subestaciones MT/BT de distribuidores radiales para su uso en la estimación de estado de sistemas de distribución. FIFth Latin – American Congress: Electricity Generation and Transmission, Nov 16^{th}-20^{th}, 2003, San Pedro San Pablo, Brasil.

[8] R. M. Pringles y D. G. Colomé,. Pseudo-mediciones de Carga Activa y Reactiva en Subestaciones MT/BT. XI ERIAC, Ciudad del Este, Paraguay, mayo 2005.

[9] D. G. Colomé, R. M. Pringles y Dölling O.: Generación de pseudomediciones de carga en subestaciones MT/BT de distribuidores radiales utilizando redes neuronales. CIDEL Argentina 2006, Bs.As, noviembre 2006.

[10] Rung-Fang Chang, Rong-Ceng Leou and Chan-Nan Lu: Distribution transformer load modeling usig load research data. IEEE Transactions on power delivery, vol.17,N°2, April 2002, pp655-661.

VI. Biographies

Delia G. Colomé was born in 1959. She obtained the Electronic Engineer degree in 1985 from Universidad Nacional de San Juan. Since 1983, she has been a researcher at Instituto de Energía Eléctrica, Universidad Nacional de San Juan, Argentina. During this time, she has worked as project manager and as senior engineer in numerous technical support projects in Argentina and different Latin-American countries. Currently, she is a Professor in the Undergraduate and Postgraduate programs at Instituto de Energía Eléctrica. Her main fields are control and supervision of power systems, modelling and simulation of power systems, and the development of computational tools for engineering teaching.

Carlos Enrique de la Vega was born in San Juan, Argentina, on July 26th, 1944. He graduated as Electromechanical Engineer from the Cuyo National University, Argentina. De la Vega is professor of electrical engineering at San Juan National University and researcher of the Electric Energy Institute of this University. His research deals with methods and algorithms for electric systems supervision and control on real time and study modes.