Abstract—The paper addresses the problem of observability in poorly measured distribution networks (DNs). In the lack of redundancy and statistical information about the measurements an innovative approach is proposed: it consists in minimizing the sum of the squares of the differences between measured and estimated values of the quantities provided by the measurement equipment present in the system. The proposed technique is based on the Interior Point method. The benefits of the approach in terms of observability improvement are illustrated by simulations involving realistic MV distribution system models. The results presented in the paper represent a part of the INGRID 2 project, which is the product of the collaboration among Politecnico di Milano, SIEMENS SpA and Università degli Studi di Milano and represents a tool developed to answer the above-mentioned needs of the Distribution System Operator (DSO).

Keywords— Smart Grid; Distribution Networks; Dispersed Generation

I. INTRODUCTION

Historically, DNs have been planned, designed, and operated as passive systems. Nowadays the remarkable expansion of dispersed generators (DG) in the DNs represents a major challenge: the distribution companies have to start behaving as a local DSO similarly to the Transmission System Operators (TSOs), i.e. to actively manage the DN. Thus, a key element in the future DNs will be achieving and maintaining the observability of the network to provide inputs to various DSO functions such as voltage and power flow control.

The percentage of investments into measurement equipment is much more reduced than the increase of DG penetration and the situation is very similar to the past: a limited set of measurements in the primary substations and in some secondary substations are available. The equipment is mostly old and the precision class is inappropriate for classical state estimation as it was installed for other purposes, (e.g. input signal for the protection systems). Moreover, the measurements are not synchronized but averaged and collected at different moments. On the other hand, it is not physically possible to install measurement equipment in many buses of a real DN as they are buried welded junctions between various cables. All these make impossible the application of classical state-estimation techniques adopted for the transmission system, as there is no sufficient redundancy, synchronization and statistical characterization of the available information.

Many researchers have addressed the issues of DN observability and State Estimation (SE) proposing different approaches [1]-[6]. Many approaches, such as in [1]-[3][6] tend to use the traditional least square methods by introducing a large number of pseudo-measurements for loads and generators. But in real DNs the loads and generators profiles are determined based on the annual energy consumption from the previous years [7]. This means that there is no statistical information available so it is impossible to correctly use them as pseudo-measurements.

Introducing a large number of pseudo-measurements is meaningless if these represent critical measurements. Trying to achieve the minimum redundancy by adding the large number of pseudo-measurements will deteriorate the quality of SE applied to DN. Some approaches, such as in [4] propose using the Phasor Measurement Units (PMUs), but this type of equipment is expensive and most of the DSOs do not use it. Last, a three or multi-phase approach [3]-[6] is not applicable for real MV grids: the loads are generally balanced and the cables parameters (especially mutual coupling) are not known.

Hence, it is necessary to design suitable innovative techniques to improve as much as possible the observability of the DN. One approach was introduced by the authors in [8]. The procedure was designed considering only the measurements in the primary substations together with historical load and generation profiles which allowed very simple and fast computations, neglecting the power flow (PF) equations. In this paper, the measurements in the secondary substations are also considered, and the PF constraints can not longer be avoided. Thus, an optimization based procedure is proposed. The problem is formulated such that the lack of redundancy and statistical information for the measurements is mitigated.

The functionality proposed in this paper was developed under the framework of the Ingrid project [8]-[11] which was started in 2010 thanks to collaboration among Politecnico di Milano, Università degli Studi di Milano and Siemens SpA. The goals of the project were to develop new tools for DSO Control Center useful for both off-line analysis and real-time operations. The project involved developing (i) the system architecture, i.e. the integration of the network calculations and
control software with the SCADA systems currently in use on DSO control centers; (ii) PF and short-circuit calculation functions; (iii) network observability improvement and (iv) voltage control functions. The resulted Distribution Management System (DMS) is currently in use in various smart-grids pilot projects in Italy.

II. PROPOSED METHODOLOGY

A. Available data

Generally in Italy, the information currently available to the DSO is of two types: (i) standard load and generation profiles and (ii) a set of measurements at the primary and secondary substations. In what regards the first category, the real and reactive power demand \((P_L^0, Q_L^0)\) and generation \((P_G^0, Q_G^0)\) profiles are known through an appropriate processing of the historical data that gives "standard" curves for various loads and generators based on the annual energy consumption.

Then, every 10-15 minutes, a set of measurements is available as averaged values over time (Fig. 1):

- \(V_{est}^m\): voltage magnitude at HV/MV busbars;
- \(P_{branch}^m, Q_{branch}^m\): real and reactive power flows through the branches directly connected to the DN substations, measured at the connection point;
- \(I_{branch}^m\) the magnitude of the currents through the branches directly connected to the DN substations, measured at the connection point;
- \(P_L^m, Q_L^m\): the demanded real and reactive power;
- \(P_G^m, Q_G^m\): the real and reactive power produced by the generators.

![Fig. 1. Available information in the substations of a DN grid: a. Voltage measurements; b. Branches current measurements; c. Branches real and reactive power flow measurements; d. Load and generation measurements.](image)

In the objective function (OF) of (1), the slack variables \(\alpha_i\), contained in the vector \(\alpha\), are the slack variables; \(N_m\) is the number of available measurements; \(f_p\) and \(f_Q\) are the PF equations; \(x_i^m\) are the available measurements in the considered DN, contained in the vector \(x^m\); \(V_M\) and \(V_A\) are the vectors of the bus voltage magnitudes and phases, excluding the slack bus.

In the objective function (OF) of (1), the slack variables, \(\alpha_i\), are scaled with respect to the measured quantities: in the absence of any statistical information regarding the quality of the measurements, in particular the type of distribution and the standard deviation of the measurements with respect to the exact value, it is very difficult to properly weight the slack variables in the OF. Introducing typical values for the standard deviations may force the optimization solver to give unrealistic results in many cases.

Then, defining an OF as the sum of the squares of \(\alpha_i\) may give many bad results since the absolute errors would be minimized without considering that various measurements can be very different in terms of numerical values (10 to 1000 times different). This could give very high relative errors between the estimates and corresponding measurements. Thus, minimizing the OF in (1), which ideally is zero, minimizes the relative errors in a balance manner.

C. Vector of state variables

Considering the available set of measurements defined in the previous paragraph (Fig. 1) the vector of state variables associated with this set is defined as:

\[
x^{est} = \begin{bmatrix} V_M & V_A & I_{branch\, re}^T & I_{branch\, im}^T & P_{branch} & Q_{branch} \end{bmatrix}^T
\]  

(2)

where:
- \(I_{branch\, re}\): the vector of the real parts of the branch currents for the branches with current measurements in p.u.;
- \(I_{branch\, im}\): the vector of imaginary parts of the branch currents for the branches with current measurements in p.u.;
- \(P_{branch}\): the vector of branch real powers for the branches with power measurements in p.u.;
- \(Q_{branch}\): the vector of branch reactive powers for the branches with power measurements in p.u.
Thus, the vector of associated slack variables consists of:

\[ \alpha = [a_P \ a_Q \ a_V \ a_{I_{branch}} \ a_{\bar{I}_{branch}} \ a_{\bar{Q}_{branch}}] \]  

(3)

where:

\( a_P \) : the vector of slack variables pertaining to the real power injections of the non-empty buses;

\( a_Q \) : the vector of slack variables pertaining to the reactive power injections of the non-empty buses;

\( a_V \) : the vector of slack variables pertaining to \( V^m \);

\( a_{I_{branch}} \) : the vector of slack variables pertaining to \( I^m_{branch} \);

\( a_{\bar{I}_{branch}} \) : the vector of slack variables pertaining to \( P^m_{branch} \);

\( a_{\bar{Q}_{branch}} \) : the vector of slack variables pertaining to \( Q^m_{branch} \);

D. Objective function

Considering the vector of the slack variables defined by (3) and the general OP defined by (1), the particular form of the objective function is given by:

\[
\min \sum_{k=1}^{N_{bus}} \left( \frac{\alpha_{P_k}}{P^m_{G_k} - P^m_{I_k}} \right)^2 + \sum_{k=1}^{N_{bus}} \left( \frac{\alpha_{Q_k}}{Q^m_{G_k} - Q^m_{I_k}} \right)^2 + \sum_{n=1}^{N_{VIPQ}} \left( \frac{\alpha_{VIPQ}}{VIPQ^m} \right)^2
\]

(4)

where:

\( N_{bus} \): the number of buses with completely measured injected powers (see Fig. 1, d);

\( N_{VIPQ} \): the total number of voltage and branch powers and currents measurements (see Fig. 1);

\( a_{VIPQ} \): vector holding \( a_V \), \( a_{I_{branch}} \), \( a_{\bar{I}_{branch}} \), \( a_{\bar{Q}_{branch}} \);

\( VIPQ^m \): vector holding the voltage and branch measurements.

It should be noted that regarding the real and reactive power injections, only the slacks pertaining to buses with completely known load and generation are included in (4) since only these measurements can be matched. Then, if one of the measurements, by which the slack variables are scaled in equation (4), is zero, or near zero, a defined base measurement is used instead of the real measurement to avoid division to very small numbers. Experience showed that using a base measurement of 1 kVA, and corresponding current base measurement, is a good choice.

E. Linear and nonlinear equality constraints

Every optimization problem is subject to a certain number of linear and/or nonlinear equality constraints. To ensure that technical and physical limitations of the network are correctly respected, an appropriate set of linear and nonlinear equality constraints has to be added to the problem:

1) Power flow equations

The PF equations are needed to assure a correct operating point of the network. Three cases can be distinguished depending on the available load and generation measurements:

- buses without load and generation, i.e. empty buses:
  \[ f_{P_k}(V_M, V_A) = 0 \]
  \[ f_{Q_k}(V_M, V_A) = 0 \]
  (5)

- buses with connected loads and/or generators but not measured or partially measured (e.g. some loads), such that the total nodal injected power is not known:
  \[ P^m_k - f_{P_k}(V_M, V_A) + \alpha_{P_k} = 0 \]
  \[ Q^m_k - f_{Q_k}(V_M, V_A) + \alpha_{Q_k} = 0 \]
  (6)

It is necessary to highlight that the slack variables used in equation (6) are not present in the OF (4) as the injected powers are not completely measured; however their lower and upper bounds are defined in accordance to the measured data. In (5) and (6):

\( P^0_k \): is the initial real injected power at bus \( k \) derived from the initial profile, \( P^0_k = P^0_{GR} - P^0_{k} \);

\( Q^0_k \): is the initial reactive injected power at bus \( k \) derived from the initial profile, \( Q^0_k = Q^0_{GR} - Q^0_{k} \);

- buses with connected loads and/or generation completely measured. The nodal injected power is measured, i.e. \( P^m_k = P^m_{GR} \) and \( Q^m_k = Q^m_{GR} \):
  \[ P^m_k - f_{P_k}(V_M, V_A) + \alpha_{P_k} = 0 \]
  \[ Q^m_k - f_{Q_k}(V_M, V_A) + \alpha_{Q_k} = 0 \]
  (7)

Only in this case, the slack variables are present in the OF and are subject to upper and lower bounds given by the errors of the measurement apparatus:

\[ -\varepsilon^m_{P_k} \cdot P^m_k \leq \alpha_{P_k} \leq \varepsilon^m_{P_k} \cdot P^m_k \]
\[ -\varepsilon^m_{Q_k} \cdot Q^m_k \leq \alpha_{Q_k} \leq \varepsilon^m_{Q_k} \cdot Q^m_k \]

(8)

where \( \varepsilon^m_{P_k} \) and \( \varepsilon^m_{Q_k} \) are coefficients that take into account the total measurement errors; since these quantities are not known, reasonable values will be given such to not negatively influence the convergence of the OP (e.g. 10%).

2) Measured voltage constraints

For the buses where voltage measurement equipment is installed, the following constraint must be respected:

\[ V_M - V^m + a_V = 0 \]

(9)

3) Measured current constraints

For the branches where current measurement equipment is installed (from-to or to-from direction), a set of constraints need to assure that the measurements will be match. For this, the complex branch currents need to be computed as:

\[ I_{branch\_re} = \text{Re}(Y_{branch\_V} \cdot V) = 0 \]
\[ I_{branch\_im} = \text{Im}(Y_{branch\_V} \cdot V) = 0 \]

(10)

and the current magnitude can be constrained to the measured value using:

\[ \sqrt{I_{branch\_re}^2 + I_{branch\_im}^2} - ||I^m_{branch} + \alpha_{I_j}|| = 0 \]

(11)

In (10) and (11):

\( V \): the vector of complex bus voltages, \( V = V_M e^{jV_A} \);

\( Y_{branch} \): the branch admittance matrix computed according to the buses where the current measurements are made.
4) Measured power constraints

For the branches where real and reactive power measurement equipment is installed (from-to or to-from direction), a set of constraints needs to be defined such to assure that the respective powers will match the measurements. For this, the complex branch powers need to be computed as:

\[ P_{branch} = \text{Re}(V \cdot \text{conj}(Y_{branch} \cdot V)) = 0 \]
\[ Q_{branch} = \text{Im}(V \cdot \text{conj}(Y_{branch} \cdot V)) = 0 \]  

and the branch powers can be constrained to a value close to the measurement using:

\[ P_{branch} = P_{branch}^m + \alpha P_{branch} = 0 \]
\[ Q_{branch} = Q_{branch}^m + \alpha Q_{branch} = 0 \]

F. Upper and lower bounds

To prevent the convergence of the defined OP to technically unfeasible operating points (e.g. operating points in which the DN would be disconnected from the main grid due to the protection actions) appropriate lower and upper bounds have been adopted for the variables of the OP as shown in Table I. These values are set according to the DSO experience and expressed in per unit considering a base power of 100 MVA. Since the powers in DN buses are generally at maximum few hundreds of kVA, the limits in Table I were set such to provide large margins for any DN.

<table>
<thead>
<tr>
<th>Variable</th>
<th>LB</th>
<th>UB</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{m} )</td>
<td>1.1 p.u.</td>
<td>0.9 p.u.</td>
</tr>
<tr>
<td>( \alpha )</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>( \alpha \text{conj} )</td>
<td>-10 or (-1^{m} \cdot \alpha \text{conj}^m / Q_{m} )</td>
<td>10 or ( \alpha \text{conj}^m \cdot \alpha \text{conj} / Q_{m} )</td>
</tr>
</tbody>
</table>

III. RESULTS

The proposed optimization model was implemented in MATLAB and the “fmincon” native function was used to find the solution to the OP. In order to facilitate and reduce the computation time, the constraints and OF gradients and hessians were defined.

To evaluate the performances of the optimization model tests have been performed on many realistic DNs characterized by different number of buses, feeders and DG; among these, two representative networks are reported in the following paragraphs. The test procedure involved generating a large number of measurement scenarios: large deviations were introduced in the standard load/generation profiles using a Gaussian distribution set to generate random numbers in the range of ±80% of the initial quantities; then PF were run to obtain the measurements. Once the set of measurements was obtained, noise was added to the measured values using a Gaussian distribution set to generate random numbers in various ranges with respect to the initial quantities.

A. 9-bus test system

The first investigated DN is the small network depicted in Fig. 2. This test system was chosen to emphasize in details the features of the proposed procedure. The network consists of a 7 bus feeder with load distributed among its buses and with a secondary substation where a generation plant is connected. The nominal load of the network is around 4.5 MVA while the nominal power of the generator is 2.4 MVA. Both the primary and secondary substations are measured as shown in Fig. 2.

![Fig. 2. The 9-bus distribution network.](image-url)

To test the proposed procedure, a set of 500 operation scenarios were generated as described above. In the absence of any procedure to improve the observability of the network, the DSO would have to rely on the results of the PF computed using the standard load/generation profiles. Table II shows the mean values and standard deviations of the estimation errors for the bus voltage magnitudes and phases in % when the standard profiles are used.

The voltage angles estimation error is at least 20%, while the voltage magnitude estimation error reaches an average of 1.5% and a standard deviation of 1% for the bus at the end of the feeder (bus 8).

![Fig. 3. Voltage magnitude at bus 8: real vs standard profiles.](image-url)

Table III shows the values of standard deviations of the estimation errors for the power injections at bus 1 and 9 in % when the standard profiles are used. The values of Table III are very high as the error of the standard profiles in terms of load and generation are up to 80% for each single load or generator. Table III shows that the estimation of both the power...
exchange with the HV grid and the power produced by the generator plant is very bad and, in consequence, no control action is possible to improve the voltage profile of the feeder.

In conclusion, the DN is unobservable and uncontrollable if only the standard profiles are considered. The proposed OP has been run for the 500 scenarios in three cases:

I. Case I: the exact measurements are used;
II. Case II: the voltage measurements are randomly perturbed by maximum ±1% while the remaining measurements by maximum ±3%;
III. Case III: the voltage measurements are randomly perturbed by maximum ±2% while the remaining measurements by maximum ±5%.

The voltage measurement is generally more precise than other measurements, hence the values reported above. Table IV depicts the mean values and standard deviations of the estimate errors for the measured quantities with respect to the exact values of the measurements for all the cases. In Case I, when the measurements are exact, the estimates match very well the measured values, the errors being insignificant. When noise is introduced in the measurement profile (Case II and III), the procedure converges to a point where the estimates are as close as possible to the exact measurements. About the errors, they are congruent with the introduced noise. For example, in Case 2, the worst estimated current is $I_{2,3}$ and the mean estimation error w.r.t. the exact measurement is around 1% while the standard deviation is 0.7 % – see Table IV; in the same time, the set of current measurements given to the OP was randomly perturbed by maximum ±3%.

Table IV. 9-bus DN estimate errors with respect to the exact measurements

In what regards the network observability, Table V reports the major improvements in the states of the system while Fig. 4 illustrates the dramatic improvements in the observability of bus 8 voltage magnitude. The voltage magnitude and angle errors are reported for the worst observable and most critical bus (bus 8). Expressed in absolute errors, for Case III, the average error of $V_{38}$ is $0.004$ p.u. and the maximum value is $0.011$ p.u., value reached in less than 1% of the measurement scenarios; while the average error of $V_{38}$ is $0.5^\circ$ and the maximum value is $1.6^\circ$. Clearly, the observability of the voltage profile has improved up to the point where reliable control actions can be applied.

Table V. 9-bus DN observability based on the optimization procedure

In what regards the controllability of the network, Table V shows that now the estimation of both the power exchange with the HV grid and the power produced by the generator plant are within acceptable limits and hence control actions regarding the voltage profile of the feeder and the power flows injected into the transmission network are now possible.

Concerning the injected powers along the feeder (at buses 3, 4, 5, 7 and 8), their observability is not improved at all as there is no information available regarding their actual values and they are free variables in the OP. However, it can be generally concluded that the proposed procedure majorly improves the observability of the DN up to render it controllable in various variables. Of course, in the lack of redundancy, the DN state cannot be completely known.

B. 69-bus test system

Fig. 5 depicts the second investigated DN network. It is the 69 bus network described in [12] to which 10 generation plants were added as shown in Fig. 5. The figure also shows the measurement locations and their types: the measured substations are depicted in detail. As with the previous DN, 500 measurement scenarios were defined and run for the 3 defined cases. Moreover, 3 configurations for the measurement types and locations were defined:

I. Configuration I: the base case depicted in Fig. 5;
II. Configuration II: same as Configuration I, but with the current measurements changed to power measurements;
III. Configuration III: same as Configuration III, but with branch power measurements added at substations 57, 59 and 62.
Table VI shows the results of the OP for all the defined measurement configurations and cases in terms of mean relative errors of the estimates with respect to the measurements and their standard deviations. Since there is a large number of measurements, only the worst results are shown for each type of measurements: generally, the estimate errors are much smaller than the reported maximum case. The results of Table VI show that the procedure has found very good solutions where the estimates are as close as possible to the exact measurements, the errors being congruent with the introduced noise.

**TABLE VI. 69-BUS DN ESTIMATE ERRORS WITH RESPECT TO THE EXACT MEASUREMENTS**

<table>
<thead>
<tr>
<th>%</th>
<th>Configuration I</th>
<th>Configuration II</th>
<th>Configuration III</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>Mean</td>
<td>Std.</td>
<td>Mean</td>
</tr>
<tr>
<td>( F_{\text{m2}} )</td>
<td>2E-2</td>
<td>1E-2</td>
<td>0.3</td>
</tr>
<tr>
<td>( P_{\text{x1}} )</td>
<td>1E-3</td>
<td>5E-4</td>
<td>1.6</td>
</tr>
<tr>
<td>( Q_{\text{x1}} )</td>
<td>1E-4</td>
<td>7E-5</td>
<td>1.5</td>
</tr>
<tr>
<td>( P_{\text{x2}} )</td>
<td>2E-4</td>
<td>6E-5</td>
<td>1.6</td>
</tr>
<tr>
<td>( Q_{\text{x2}} )</td>
<td>5E-5</td>
<td>4E-5</td>
<td>1.5</td>
</tr>
<tr>
<td>( Q_{\text{a}} )</td>
<td>4E-5</td>
<td>3E-5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

**Fig. 5. The 69-bus distribution network: Configuration I.**

Regarding the observability of the network, Figs. 6÷9 depict the estimation errors in terms of means and standard deviation for the voltage magnitudes and phases of the buses at the end of the main feeder, i.e. bus 27, and of its deviations (secondary feeders), i.e. buses 35, 46, 50, 52, 65, 67, 69. The results are shown for all the measurement configurations, including also the results given by the standard profiles, for the case with the most severe measurement noise (Case III).

**Fig. 6. End-feeder buses voltage magnitude mean estimation error: Case III**

**Fig. 7. End-feeder buses voltage magnitude standard deviation: Case III**

When branch measurements in the feeders are available (all buses except bus 65 in Figs. 6÷9) the estimation of the voltage magnitudes and angles are very good up to render the voltage profile observable and, hence, make control actions possible. Strictly referring to the feeders where branch measurements are available, an improvement in the voltage angle observability is noticed when changing the branch measurements from currents to powers, but no improvement in the voltage magnitude observability. This happens as the voltage drops in the lines are strongly dependent on the current magnitudes, already well...
estimated in Configuration I, while the voltage angles are more sensitive to real/reactive power flows transmitted by the network which are better estimated in Configuration II.

Moreover, the estimation of the nodal powers for the buses located in the proximity of the branch measurements are improved when the type of branch measurement is changed from current magnitude to powers. Table VII depicts the errors in absolute values for the nodal powers of the buses in the vicinity of the measured bus 30 (buses 29 and 31 are transit buses). The major improvement when the measurement type is changed can be seen in the buses most near to bus 30: buses 28 and 32. For the rest of the buses, no major improvement is achieved. Moreover, even if buses 28 and 32 are almost equally electrically distant with respect to bus 30 (Z_{28,30}=0.18 p.u. and Z_{32,30}=0.14 p.u.) the major improvement is achieved for bus 28 as this bus is located between measured buses: 3 and 30, while bus 32 is not.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Configuration I</th>
<th>Configuration II</th>
</tr>
</thead>
<tbody>
<tr>
<td>P_28</td>
<td>15.8</td>
<td>13.8</td>
</tr>
<tr>
<td>Q_28</td>
<td>13.5</td>
<td>9.0</td>
</tr>
<tr>
<td>P_30</td>
<td>7.2</td>
<td>5.7</td>
</tr>
<tr>
<td>Q_30</td>
<td>7.0</td>
<td>5.5</td>
</tr>
<tr>
<td>P_32</td>
<td>9.5</td>
<td>7.9</td>
</tr>
<tr>
<td>Q_32</td>
<td>6.0</td>
<td>4.3</td>
</tr>
<tr>
<td>P_34</td>
<td>10.4</td>
<td>8.8</td>
</tr>
<tr>
<td>Q_34</td>
<td>8.9</td>
<td>5.7</td>
</tr>
</tbody>
</table>

For the feeder where the branch measurements are initially missing (buses 53÷65), the voltage profile estimation is much worse, especially regarding the voltage angle: for Configuration I and II, the estimation of the voltage angle of bus 65 is more or less as bad as using the standard profiles; then, when the power branch measurements are available, it improves up to observable values.

Regarding the controllability of the network, all the generation plants and the power exchange with the HV network are measured and the estimation of their output is very good (see Fig. 5 and Table VI). Therefore, the voltage profile and the power exchange with the HV grid are controllable through the adjustment of the generation plants output.

Finally, it should be mentioned that all the tests have been performed on a computer equipped with an Intel Core i5, 2.8 GHz processor and 8 GB of RAM. Considering all the tested cases and configurations, the average computation time for one scenario for this network resulted in ≈ 12÷13 s. Since the measurement profiles are updated every 10÷15 minutes, this number shows that no matter how bad the starting point is the solution of the OP is computed within acceptable times for online applications.

IV. CONCLUSIONS

In this paper an optimization procedure to improve the observability of the poorly measured distribution networks is proposed. The methodology mitigates the lack of redundancy and statistical information regarding the measurements in the DN and exploits at maximum the poor information currently available in DNs.

To find the solution to the OP an interior-point method is used. The tests performed on various DNs show the robustness and the good performances of the methodology. The observability of the voltage profile, of the power plants output and of the power exchange with the HV grid are dramatically improved, up to the point where some control actions are possible.

REFERENCES