

# Local and Central Algorithms for Distributed Generation Micro-dispatch Control

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**Abstract:** Global growth of distributed generation, especially photovoltaic, has given rise to new markets and new problems: large injection of power at daily intervals without increasing in the level of consumption. This scenario has already created, in certain places, overvoltage problems, harmonic distortion, etc. In Brazil, the standards regulate the connection of photovoltaic inverters, however, the control is not yet subject to standardization. For this reason, this paper presents a proposal of local and central algorithms for this power injection control in accordance with the solutions of problems such as the lack of standardization in the communication protocol of the inverters. The results of the pilot plant application are also presented.

**Resumo:** O crescimento global da geração distribuída, especialmente fotovoltaica, deu origem a novos mercados e novos problemas: grande injeção de energia em intervalos diários sem aumentar o nível de consumo. Este cenário já criou, em determinados lugares, problemas de sobretensão, distorção harmônica, etc. No Brasil, as normas regulam a conexão de inversores fotovoltaicos, porém, o controle ainda não está sujeito à padronização. Por este motivo, este trabalho apresenta uma proposta de algoritmos local e central para este controle de injeção de energia, de acordo com as soluções de problemas como a falta de padronização no protocolo de comunicação dos inversores. Também são apresentados os resultados da aplicação da planta piloto.

**Keywords:** Algorithms; communication; distributed generation (DG); inverter; power injection.

**Palavras-chaves:** Algoritmos; comunicação; geração distribuída; injeção de potência; inversor.

## 1. INTRODUCTION

The generation of photovoltaic energy is widespread worldwide and has been growing exponentially in the Brazilian electricity system. In world terms today, the installed power of photovoltaic generation reached 400 GWp as can be seen in Fig. 1 (IEA 2018). There has been a sharp increase since the year 2010, as well as a significant participation of the Americas of approximately 20% in the world scenario.

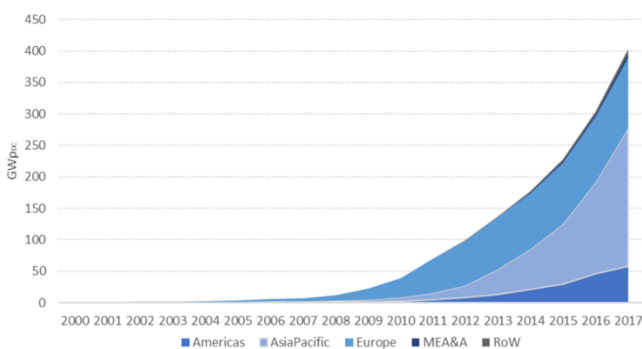


Fig. 1 World photovoltaic generation (IEA 2018).

The numbers presented in Fig. 1 refer to photovoltaic generation as a whole, i.e., these systems can be divided into centralized generation and distributed generation. Centralized generation consists of large power plants, reaching hundreds of Mega Watts, which are usually connected to the high voltage system. Distributed generation, however, consists of small systems, usually installed in residential and commercial consumers, connected to the electricity distribution networks. In Brazil, distributed generation started its most accentuated growth based on normative resolution 482 issued in April 2012 by ANEEL – Brazilian Electricity Agency (ANEEL 2012). This normative resolution, updated later by the 687 published in November of 2015 (ANEEL 2015), establishes the general conditions for the electric connection of microgeneration (up to 75 kW) and minigeration (up to 3 MW) to the electricity distribution networks, mainly defining the current energy compensation system. Fig. 2 shows the growth of micro and mini-generation connections in Brazil after ANEEL's regulation in 2012, reaching in the middle of 2017 more than ten thousand connections.

## Connections x N° consumer with credits

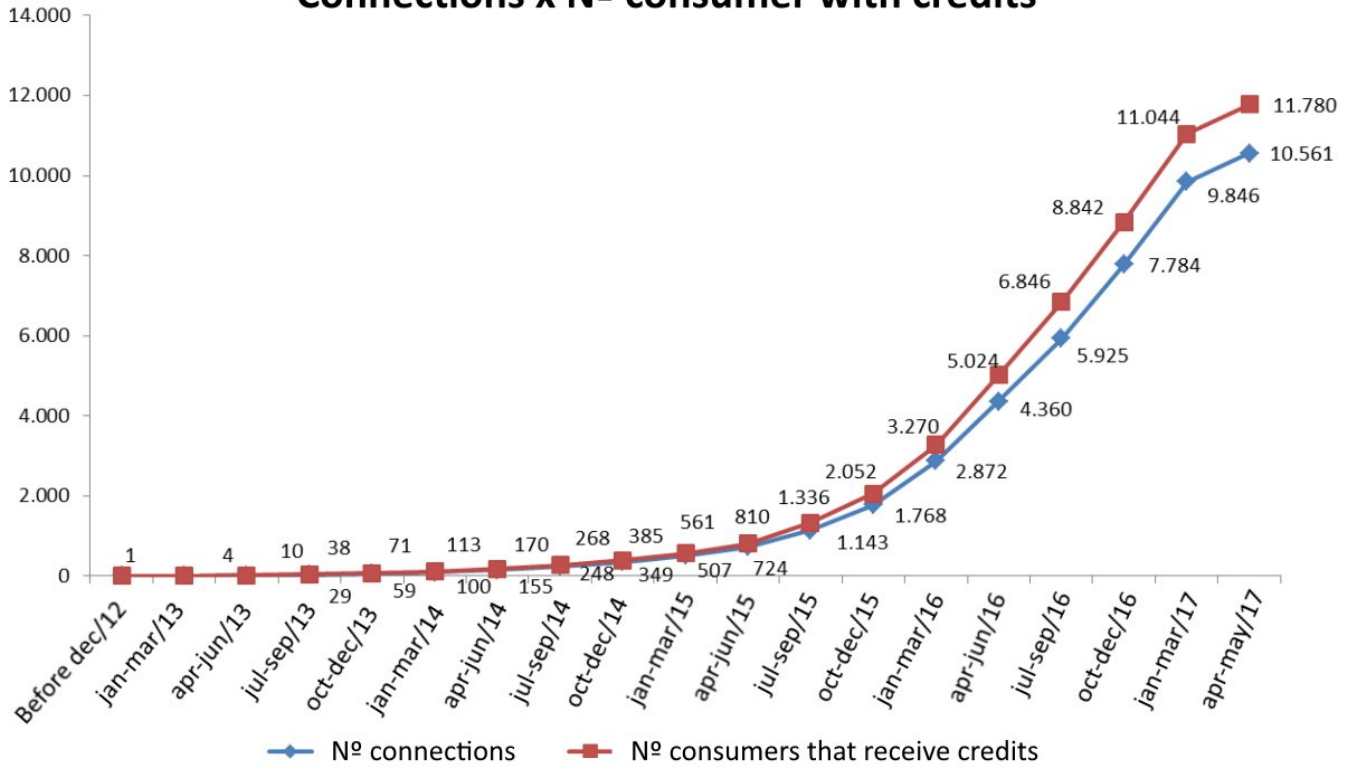


Fig. 2 Micro and mini-generation in Brazil (ANEEL 2017).

Of these connections, it is verified in Fig. 3 that almost all of them, more than 99%, are of photovoltaic generation systems.

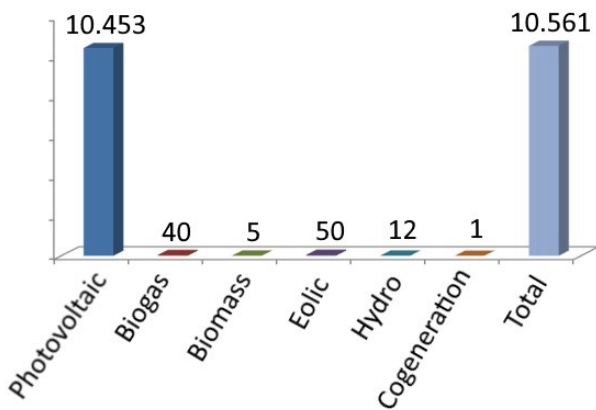


Fig. 3 Connection by source type (ANEEL 2017).

With this high insertion of distributed generation, besides the known benefits of the use of these technologies, it becomes necessary to discuss the technical difficulties inherent to this application. The main technical difficulties in the distribution networks, due to the high insertion of photovoltaic generation, are related to the fact that these DG sources are not dispatchable by the operation system, as well as having an unpredictable generation profile. Among these difficulties, it is possible to mention: overload of network components such as distribution

transformers, fluctuations of active and reactive power, problems in the operation of the protection system, voltage imbalances and overvoltages (Hashemi et al. 2017).

Considering the main technical problems due to the high insertion of distributed generation, according to Hashemi et al. (2017), the overvoltages in the distribution network represents the main limitation for DG insertion. These overvoltages occur in the distribution system when the reverse power flowing is high, which can lead to unacceptable network voltages. In extensions with predominantly residential consumers, the instant of greater photovoltaic generation usually coincides with the moments of lower consumption, a situation that corroborates the occurrence of overvoltages in distribution networks with a high level of photovoltaic generation. (Hashemi et al. 2017; Candelise et al. 2011; Oliveira et al. 2011; Ledwich et al. 2014).

In this way, it is necessary to evaluate technical solutions for the mitigation of overvoltages in the electricity distribution network with high insertion of distributed photovoltaic systems. This work presents a survey of the main solutions used to mitigate this problem.

## 2. OVERVOLTAGE MITIGATION TECHNIQUES

In Hashemi et al. (2017) it is discussed the main techniques used to prevent overvoltages in low voltage distribution systems, highlighting the following possibilities:

- 1) Electrical network reinforcement;
- 2) Application of active transformers (OLTC - on-load tap-changer);
- 3) Limitation of active power of DGs;
- 4) Reactive power control of DGs;
- 5) Demand response;
- 6) Application of energy storage systems.

Each approach presented has proven effectiveness, however, leading to varying implementation costs and difficulties. In this sense, solutions 3 and 4 stand out, that is, active power limitation and reactive power control of the DGs, since the implementation of these solutions does not require additional investments beyond the DG structure itself. Both techniques were used in the algorithm developed in the present work and detailed in the sequence.

### 2.1 Active Power Limitation

The limitation of the maximum active power of a photovoltaic system, or Power Curtailment, despite having a good efficiency to reduce overvoltage is not considered an efficient solution. This is due to the fact that, since photovoltaic energy is considered a renewable, clean energy solution, the limitation of its injection into the grid is not an acceptable solution. It is therefore agreed that active power limitation should only be applied in extreme cases, i.e. when the overvoltage can present risks to the operation of the system. Fig. 4 shows an example of the active power limitation in a system susceptible to the impact of photovoltaic generation. The active power limitation can be realized in different ways, and the dynamic mode is presented as a more efficient solution generating lower losses of generation for photovoltaic system. The dynamic mode consists of the application of an active power limiting curve (Droop-based) as a function of the voltage. In spite of presenting smaller losses of generation over time, the dynamic limitation of active power as a function of the voltage tends to penalize more the connected systems in weak bars of the system, so that an equalization system for generation losses control is necessary.

### 2.2 Reactive Power Control

Reactive power over voltage (Q-U) control is classically used in high voltage networks, transmission lines, and has a great efficiency. This is due to these networks have a low impedance relation (Resistance on Reactance). For distribution networks analysis the value of this relation tends to increase significantly, considering that smaller section conductors have greater resistivity. Thus, the Q-U control in distribution systems tends to be less effective when compared to high voltage systems; yet this method presents satisfactory results in distribution systems.

The Q-U control of DGs sources in distribution systems can be implemented locally or centrally. The local control

is performed in a similar way for dynamic control of active power limitation, i.e., based on a Droop curve to determine the reactive power set point as a function of the voltage. In Hashemi et al. (2017) is presented two curves for reactive power local control: power factor as function of active power and reactive power as function of voltage. Fig. 5 shows an example of the two curves mentioned above.

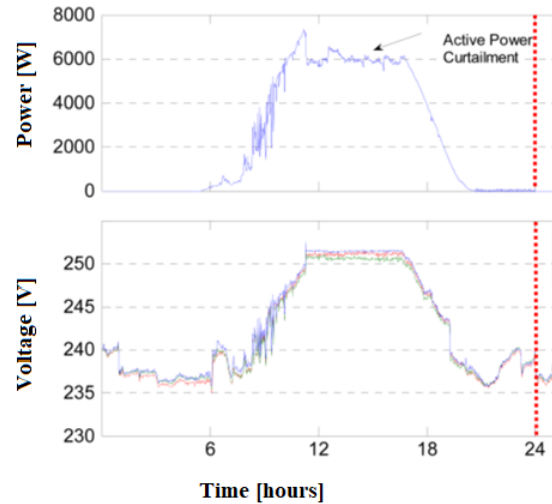


Fig. 4 Active power limitation and voltage behavior for a photovoltaic system (Hashemi et al. 2017).

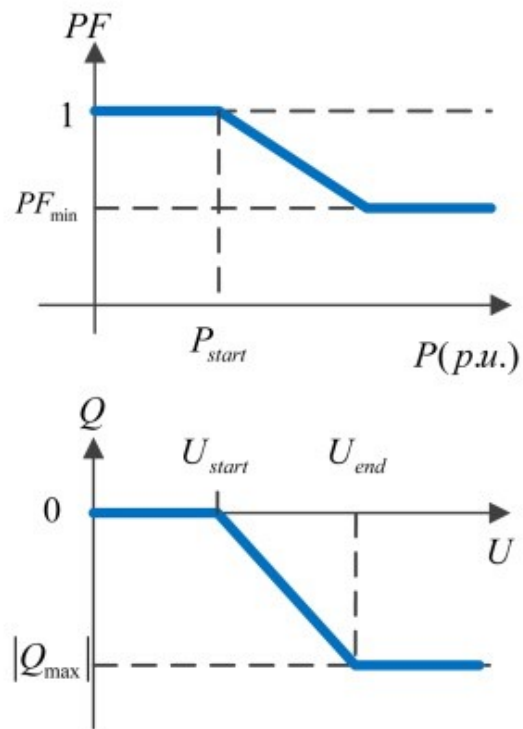


Fig. 5 Curves for reactive power control – local mode (Hashemi et al. 2017).

On the other hand, centralized control strategies can be based on the curves presented or not. Its main advantage is the possibility of more advanced evaluations and controls, such as: the reactive power equalization of all the inverters, the possibility of generating reactive power in the inverters closer to the transformer to be consumed in the more distant inverters, loss reduction among others. The main challenge

for the implementation of centralized controls is to find an attractive cost-benefit ratio, since the necessary infrastructure for communication and control of these networks is economically expensive.

### 3. PROPOSED ALGORITHMS

This paper proposes two algorithms, based on active power limitation and reactive power control techniques. The first algorithm is the local control, which aims to solve overvoltage problems. The second algorithm is a central algorithm, which has the main goal of balance the power limitation of the inverters connected in the same group.

#### 3.1 Local Control Algorithm

The local control algorithm can be divided into two main parts: data acquisition and supervision. Fig. 6 presents the flowchart of data acquisition algorithm.

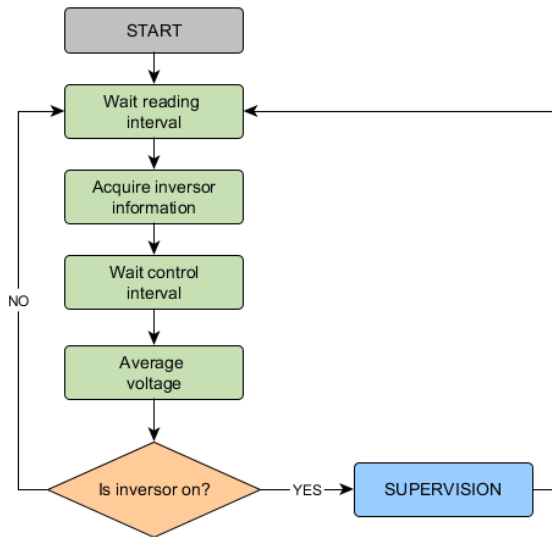


Fig. 6 Flowchart for data acquisition algorithm.

The data acquisition has two timers, which trigger the inverter data acquisition and the inverter control. For the inverter data acquisition, a command requesting the active and reactive powers is sent to the inverter (reactive power for inverters above 6 kW). Then, the average voltage is calculated with the root mean square (RMS) voltage in one minute integralized period, which is an input to the supervision.

The second part of local control algorithm, the supervision, processes the information and defines the new value for the active and reactive power limits. It considers that the active power limitation and the reactive power control generate losses to photovoltaic plant owner, thereby, the algorithm limits the inverter power only to bring the RMS voltage values to the normal range, according to the current ANEEL regulations (PRODIST – Electric Power Distribution Procedures in the National Electric System) (Prodist Módulo 8), minimizing the consumer losses.

The supervision module has the logic of three different stages of control depending on the voltage, as follows:

- Adequate Voltage (within the limits determined by ANEEL - PRODIST): Normal control stage;
- Higher Precarious Voltage (above superior limitation level of PRODIST): Activates overvoltage control stage;
- Lower Precarious Voltage (below inferior limitation level of PRODIST): Activates undervoltage control stage.

The control stages are changed after the pre-set voltage limit has been exceeded, and to return to normal stage a hysteresis (transition margin) has been programmed as shown in Fig. 7. Both the hysteresis value and the voltage values are configurable parameters within the algorithm and the values are being studied to identify the most suitable ones.

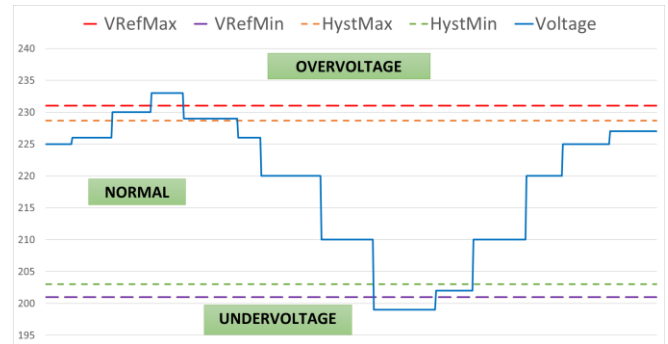


Fig. 7 Limits for voltage control.

Furthermore, the supervision has three operations mode, which are defined according to inverter nominal power:

- For inverters with power up to 3kW the control is on or off (Control 1);
- For inverters with power between 3kW and 6kW the control limits only active power (Control 2);
- For inverters with power from 6kW the control is total, limiting both active power and reactive power (Control 3).

#### 3.1.1 Control Mode 1

In Control Mode 1, the inverter does not allow active or reactive power limitation and therefore the control only turns the inverter on or off. When an overvoltage is detected and the inverter is running, the command is sent to switch the inverter off. When the normal voltage is detected and the inverter is switched off, the command is sent to switch the inverter on.

#### 3.1.2 Control Mode 2

In Control Mode 2, only the active power limitation control of the inverter is performed. When overvoltage is detected, the value of the active power limitation in percentage is defined by (1).

$$P_{lim} = (P_{pu} + P_{delta}) - (k_p * (v_{pu} - V_{RefMax})) \quad (1)$$

Where:

$P_{pu} = \frac{P_{actual}[W]}{P_{Max}[W]}$  – current active power acquired from inverter divided by maximum active power from one;

$P_{delta}$  is the delta value calculated by central control;

$v_{pu} = \frac{V_{rms}[V]}{V_{nom}[V]}$  [dimensionless] – where  $V_{rms}$  is RMS measured voltage and  $V_{nom}$  is pre-defined nominal system voltage;

$k_p$  [dimensionless] is the controller gain for active power;

$V_{RefMax}$  [pu] is the maximum reference voltage without control.

When undervoltage is detected, the active power limit is set to the maximum (100%). If the voltage is adequate, the active power limit is set to the maximum, but the configuration is performed gradually increasing by 20% each cycle of the algorithm.

### 3.1.3 Control Mode 3

In Control Mode 3, total inverter control is achieved by limiting both active and reactive power. At the adequate voltage range the control sets the maximum active power and reduce the reactive power level to zero, just as before the maximum active power is set up gradually. In the overvoltage mode, active power limitation and inductive reactive power injection are performed. While in undervoltage mode the active power is set to the maximum and the injection of capacitive reactive power occurs. The active power limitation is calculated according to (1), and the reactive power injection is calculated by (2).

$$Q_{lim} = Q_{pu} - (k_q * (v_{pu} - V_{RefMax})) \quad (2)$$

Where:

$Q_{pu} = \frac{Q_{actual}[VAr]}{Q_{Max}[VAr]}$  – current reactive power acquired from inverter divided by maximum reactive power from one;

$v_{pu} = \frac{V_{rms}[V]}{V_{nom}[V]}$  – where  $V_{rms}$  is the RMS measured voltage and  $V_{nom}$  is pre-defined nominal system voltage;

$k_q$  is the controller gain for reactive power;

$V_{RefMax}$  [pu] is the maximum reference voltage without control.

It is used  $V_{RefMax}$  value for overvoltage control and  $V_{RefMin}$  value for undervoltage control.

Using (2) for the reactive power calculation, also occurs a limitation in its value because of the maximum apparent power level pre-defined by the manufacturer.

### 3.2 Central Control Algorithm

The central control corresponds to a server that communicates with all the Controlbox connected to it. The flowchart of the central control algorithm is presented in Fig. 8. When a new connection is detected a reading configuration command is sent to the device in order to get the device ID, inverter manufacturer, local control type, quantity of inverters controlled by the Controlbox and Controlbox group.

The central control runs based on two independent timers, a reading timer and a control timer. These timers are configurable in the central control software. The reading timer sends the reading command to all devices to get voltage and power information. When a device answers the reading command, the values are saved in the device log to data history view. This information will be used later in the central control.

The control timer triggers the execution of the central control. The goal of the control is to balance the active power limitation between the devices of the same group, thus only groups with more than one inverter are controlled. With the device information read, the control goes through all the groups and verify how many devices in the group are in overvoltage and with the inverter on. If there are more than one device in the condition described, the algorithm first calculates the average of active power limitation of these devices. Then, it calculates the delta value of each device, as in (3). Otherwise, if there aren't enough devices to control, delta value is equal zero. After execute the algorithm for all the devices and groups, a configuration command is sent to each device with the delta value corresponding.

$$delta = lastDelta - k_p * (P_{lim} - avg_p) \quad (3)$$

Where:

$lastDelta$  is the previous calculated delta;

$P_{lim}$  is the current power limitation configured in the inverter;

$avg_p$  is the average of the power limitation calculated to every inverter in the group;

$K_p$  is defined by group and can be configured in the software;

Reading timer and central control timer also can be configured.

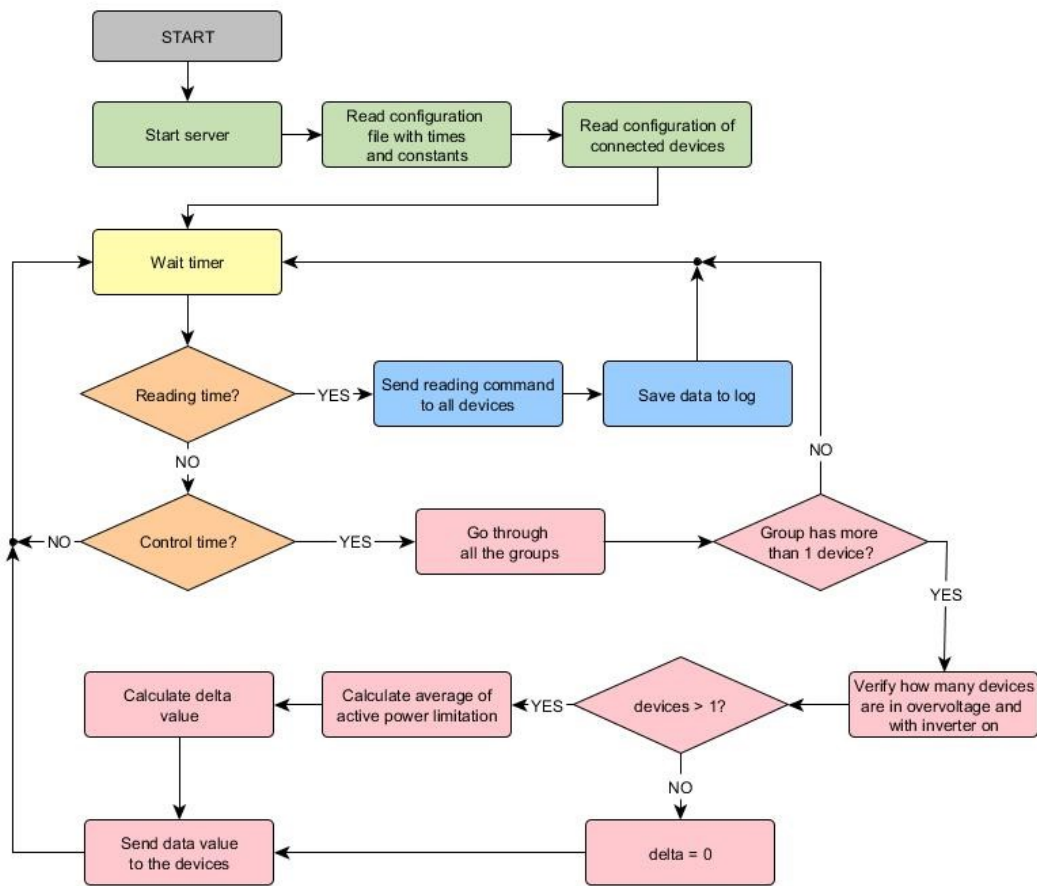


Fig. 8 Central algorithm flowchart.

## 4. RESULTS

### 4.1 Test description

For the control algorithm validation, three sets of photovoltaic plants with three Control Boxes were installed at COPEL Headquarter (Fig. 9).

Each Control Box contains all algorithms developed and all electronic circuits for the inverters communication.



Fig. 9 Setup implemented for the test: inverter, photovoltaic panels (and its maximum power) and Control Box.

As the purpose of the test was to analyze the performance of the algorithm, the maximum limits for the algorithm

operation were defined within the normal range, as presented in Table 1.

Table 1. Parameters defined for the test

Parameter	Value	Unit
Nominal voltage	220	Volts
Maximum reference voltage	1.02	Per-unit related to Nominal Voltage
Minimum reference voltage	0.98	Per-unit related to Nominal Voltage
Hysteresis	0.01	--
$K_p$ gain	2.0	--
$K_q$ gain	0.5	--

Gains  $K_p$  and  $K_q$  implemented for the control system were obtained from the observation during tests for dynamic response in steady states and under active power injection changing. It depends on system impedance and other local conditions.

### 4.2 Results analysis

After the activation of the control, data from the three Control Boxes were collected in the period between September 15 and October 29. Fig. 10-12 shows the daily mean value of: voltage registrations at the main points of connection, active power and their limits calculated according algorithm rules discussed.

## Voltage

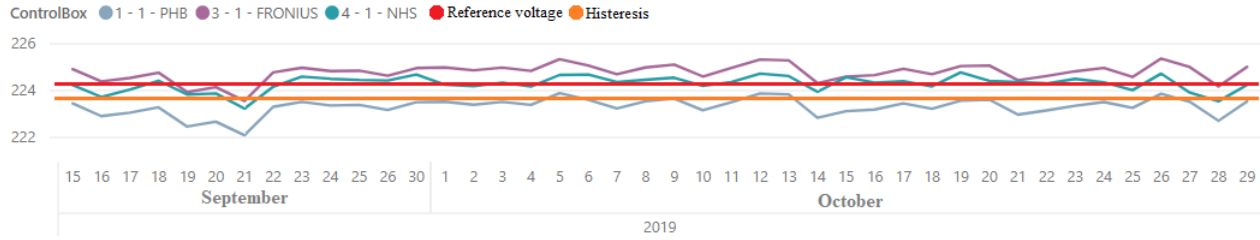


Fig. 10 Voltage measured and the limits – three Control Boxes registering and running algorithm independently.

## Active Power



Fig. 11 Active power injected by inverters under control conditions.

## Active Power Limit

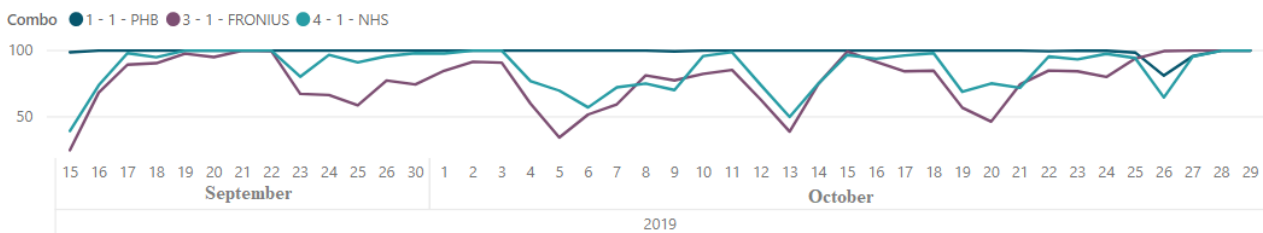


Fig. 12 Limits for active power according algorithm rules.

Observing Fig. 10-12, it is possible to highlight that, despite some variations, the values measured for three Control Boxes are similar (probably because they are in the same location under same solar conditions).

A deep analysis of the algorithm can be done in Fig. 13, where the RMS Voltage, Active Power and Active Power Limit of October 23th from 11:00 to 14:00 o'clock are shown. In the figure, it is possible to verify that there was active power control only in one of the inverters. In this case, it is possible to verify in detail the algorithm performance.

It is possible to notice that when the voltage value exceeds the set limit, the control starts the reduction of the active

power injected into the electric power grid. After the voltage value falls below the minimum hysteresis value, the algorithm determines the start of the release of the active power injection into the electric power grid. This process occurs again in another interval on the same analyzed day.

Considering that algorithm changes limit for active and reactive power just in case of voltage exceeds the limit, it is possible to conclude that in this condition, the amount of energy injected from solar sources, caused overvoltage, and control reduced this effect controlling energy injected into the electric power grid.

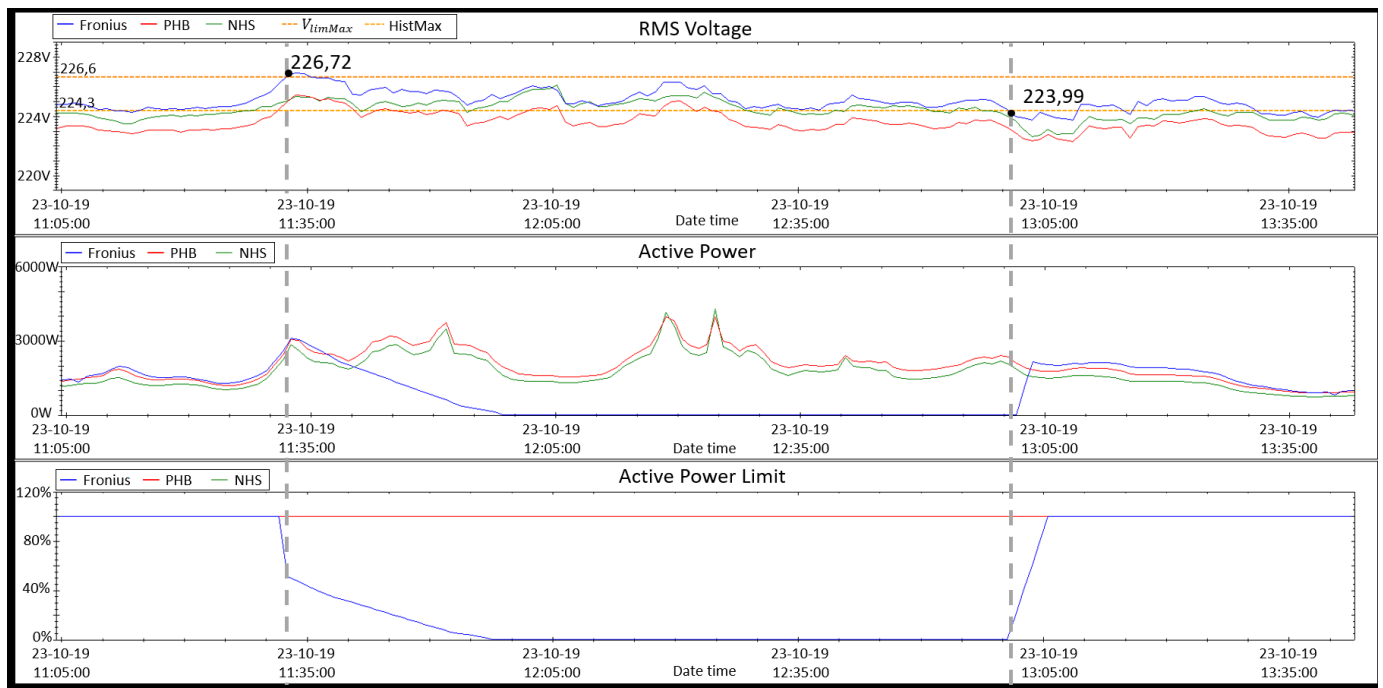


Fig. 13 Action of the active power control and result over voltage and active power.

## 6. CONCLUSIONS

It was presented and discussed some problems regarding photovoltaic systems and their interactions to electric power grid, especially overvoltage due to high level power injection.

Two new algorithms were presented and implemented; and preliminary results show that is possible to control overvoltage level controlling the solar plant energy production.

More tests and analysis are necessary in order to observe news adjustments and improve performance of the control. It is necessary to install new Control Box devices to increase the number and complexity to central control, searching new barriers to overcome.

Obviously in a scenario where more inverters are injecting energy into the grid, problems as communications and processing will appear and they will provide new parameters setup for both controls.

## ACKNOWLEDGEMENTS

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