# Adaptive Instantaneous Overcurrent Relay Settings in Real Brazilian System with Distributed Generation

F. C. Souza Júnior, H. S. Sanca, F. B. Costa, B. A. de Souza

**Abstract**— Recently a large number of small units of electric generation are being installed in the electric power distribution system in Brazil, due to the governmental investments on renewable energy. Modifications in the settings of the protection system may be caused by the high penetration of distributed generation (DG) in the electric system and parameterize the protection system for this new setting is necessary. However, this task is being made with much difficulty in many companies which use the conventional methods. In this paper, an adaptive protection scheme is proposed to determine instantaneous overcurrent relay setting. Frequency estimation was used to determine load and power supply changes in a real Brazilian system, and these modifications on the system were used to the adaptive protection block to determine the update on relays settings. The application of frequency estimation methods to adaptive overcurrent protection presented good results and improvements on the protection of the electric system.

**Index Terms**— Adaptive protection, overcurrent protection, frequency estimation, relay setting, distributed generation, distribution systems, instantaneous overcurrent reach.

## 1 Introduction

On actual Power Electric System (PES) scenario, modifications on topology and operational network are frequently. In electric distribution systems changes have been verified in a lot of cases, as: add new consumers to the grid, contingency condition, and more recently, connection of small power generators.

Renewable energy sources, such as energy based on sugar cane bagasse, wind energy, and solar or photovoltaic energy generally are used. Actually, with the connection of distributed generation (DG) in the PES the system has suffered changes and dynamic situations during the operation. In islanding condition of the DG, the parameters as voltage, current and frequency may suffer changes.

However, the protection in a power system should consider all network changes and the setting of the relay should be updated. So, for each network change, new relay settings should be executed.

Coordination of relay protection in power system is a difficult task [1]. Some authors have been proposing techniques to optimize the process of coordination to reduce the protection engineers effort [2]–[5]. However, most of these new techniques do not have a good computational performance.

To guarantee reliable system operation is necessary to control of voltages, current and the fundamental power frequency [6]. Several methods have been proposed and, most of them perform well when the signal is not distorted by harmonics or noises. In distribution systems due to the dynamic load, this system suffers high disturbs and it is usually not balanced, this causes high problems in frequency estimation [6]. Recently, a new protection philosophy proposes which relay settings could be automatically updated according to the topological or operational modifications [7–8]. These philosophies were called as adaptive protection.

On traditional protection techniques, network modifications were not considered on coordination studies, such as blinding of protection and false trip are frequent [9]. Adaptive protection scheme (APS) provides relay settings based on operational conditions. In other words, relay settings suit up to operational conditions. In distribution system, the main protection is overcurrent function [10].

The frequency of the power system plays an important role in monitoring and control the operational status of the grid or in DG systems. For reliable operation of the smart grid, it is essential to estimate the power system frequency accurately [6]. For this reason, frequency estimation algorithms have to be robust and reliable. Many algorithms are presented for fundamental frequency estimation applied in electric power systems such as: zero crossing method [11–12], adjustment of points to a pure sinusoidal waveform (APPSW) [13], hybrid method [14–15], discrete Fourier transform method (DFT) [16].

In this paper, an adaptive protection scheme is proposed to determine instantaneous overcurrent relay setting. The adaptive overcurrent protection will monitor system modifications done from the estimation of the fundamental frequency. For this end, three methods of fundamental frequency estimation applied in distribution systems in islanding operation of DG are evaluated such as: (i) Zero crossing, (ii) curve fitting and (iii) hybrid method.

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International Journal of Scientific & Engineering Research Volume 7, Issue 10, October-2016
ISSN 2229-5518

Using a distributed architecture composed of three centers [4], [17], proposed method was available in a real Brazilian sub-transmission system, owned by Eletrobrás Distributer of Alagoas (EDAL). Adaptive protection system has been built using ATP/MODELS [18–19]. The APS is composed of three centers: substation control center (SCC), control operational center (COC) and the intelligent electric device (IED). COC monitors and detects topological and operational condictions on the system. SCC center is responsible for executing all mathematic operations to determine instantaneous overcurrent relay settings. IED has the same architecture as proposed in [20–21] with one difference, the relay parameters do not upload on the device in groups that represent some operational condiction, as in some cases, it are provided from SCC center, through a communication channel, and update without any interruption on power electric system monitoring.

Results showed that in some cases, traditional protection scheme does not provide a correct performance when a change in network topology occurred. In some cases yet miscoordination was verified. However, when the proposed APS was applied, in all protection devices, was obtained good performance of the network, including when topological and/or operational modifications occurred. Another paper contribution is respect to the reduction the coordination difficulties, making the coordination study a simple and efficient process in comparison that the traditional process.

## 2 Adaptive Protection System

The adaptive power system protection is a mathematic toolkit which keeps protection coordination even when the network passes from topological or operational changes [22]. Researches have been studied several ways to do this functionality. Authors of [2] suggest a linear programming to optimal coordination maintenance of overcurrent relays, opposite topological and operational changes. On these papers traditional off-line tools techniques as power flow and short circuits to determine time dial settings of time overcurrent relays.

Regarding the system architecture [23] proposes to divide it into five areas with free access to each others information, operating on a transmission network with a high presence of DG. On the same hand [24] uses a multi-agent strategy with a power protection system (PPS) composed of three layers. In [24] only instantaneous overcurrent units are controlled by adaptive protection. The necessary parameters to calculate the instantaneous overcurrent reach must be obtained using [25].

In [17] the same architecture that [24] has been used. However, the setting of overcurrent relays it is not calculated in real-time. In the preliminary step, held in off-line mode, is necessary to do all operational possibilities of the network which will be considered in the coordination study and, with this, will be adjusted the settings for each operational scenario. Thus, APS is responsible for detection and identification all network topology scenario. This detection will be used as input of digital relays on the PES. Known the topology, IED will adopt the specific adjustment group settings to the current topology.

Based on [4], [24] a three interconnecting centers composes the PPS architecture, as shown in Fig. 1. The first center, COC, is responsible for electrical network monitoring and topological changes identification. The second center SCC is responsible for mathematics determination of setting overcurrent devices. In this paper a decentralized scheme has been used to determe the instantaneous overcurrent relays unit. This choice has been made to possibility that protective devices use moderat power processing, as yet occurs in commertial devices. As indicated in [26] the adaptive protections system can be implemented using a digital signal processor as DSP or FPGA chips. Finally, forming the third center, the IEDs does traditional digital relays task and also proposes adaptive task.

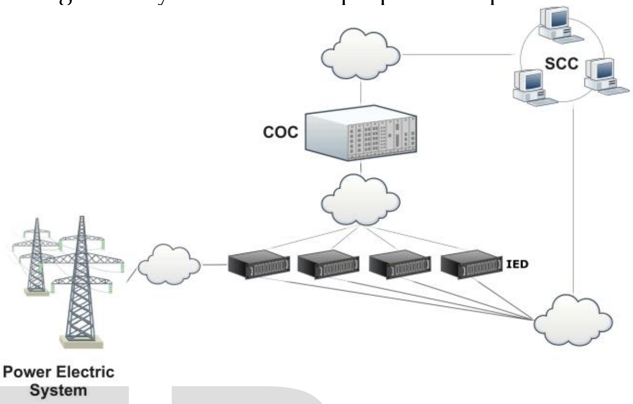


Fig. 1. Adaptive Protection System Architecture.

### 2.1 Substation Control Center (SCC)

The SCC has as main function, the monitoring and topological change detection on the electrical grid. Fig. 2 contains a detailed flow chart of SCC.

In this paper, SCC center is implemented by frequency estimation as will describe in section III.

To detect a modification in the system, the fundamental frequency of the power network system is estimated and compared with nominal frequency setting. To detect a modification on the grid, the method verifies the variation of the frequency from any modification of the system.

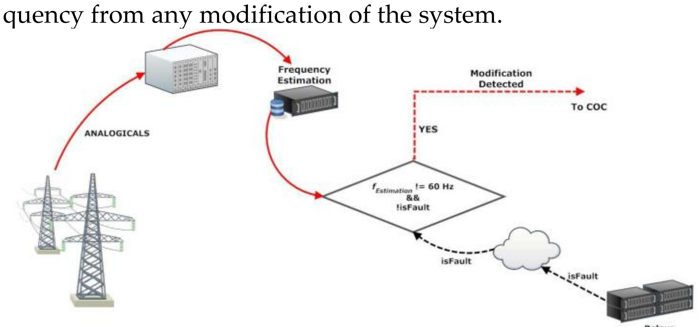


Fig. 2 - Substation Control Center (SCC).

To make a correct identification of an operational change is necessary to differ this event of a fault scenario. To do this, SCC architecture provides a communication channel for receive fault detection of relays. So, an operational modification only will be indicated if the event does not represent a fault.

When estimated frequency is different that the nominal frequency and any fault was detected, a digital message will

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ISSN 2229-5518

be sent to COC center that will be interpreted as a flag for calculation of new settings.

### 2.2 Control Operational Center (COC)

The COC is the layer where all mathematics process necessary to setting adjustments of protective devices are made.
Strictly, an uninterrupted voltage and current phasor transfer from COC to the relays would result in the need of a very fast communication channel. For this fact, decides for a duplication on COC for a relays similar architecture describes in [21], i.e., all steps blocks responsible for the tasks until the phasor estimation is present as on the relays devices as in the COC. Fig. 2 shows the COC operation architecture. According to Fig. 2 proposed APS architecture must be able to operate with current and voltage signals in more than one point of the grid. This need is due to the fact that the determination of the equivalent network depends on the knowledge of such signals at various points in the system.
Despite having the same structure of digital relays, COC does not need to make phasor estimation for all samples. The windowing process continues to be done without interruption, but the following steps: phasor estimation, calculation of the equivalent network and protective devices adjustments settings are only performed if the SCC detected any change in the electrical network.
The setting adjustments of adaptive protection devices are extremely dependent of phasor estimation routine and network equivalents. According to [9] network equivalent determination must be obtained using probabilistic relationships between voltage and current. Through routines, oriented tests were verified a shorter error value of equivalent network routines when a minimum 40 samples/cycle are used. As IED and COC uses 16 samples/cycle, sets equivalent network determinations routine to use the triple samples hate value, i.e., the mathematics calculation will be realized once every three complete cycles of samples on phasor estimation.
After determination of new adjustments settings, these parameters will be transferee to IEDs thought communication channel.

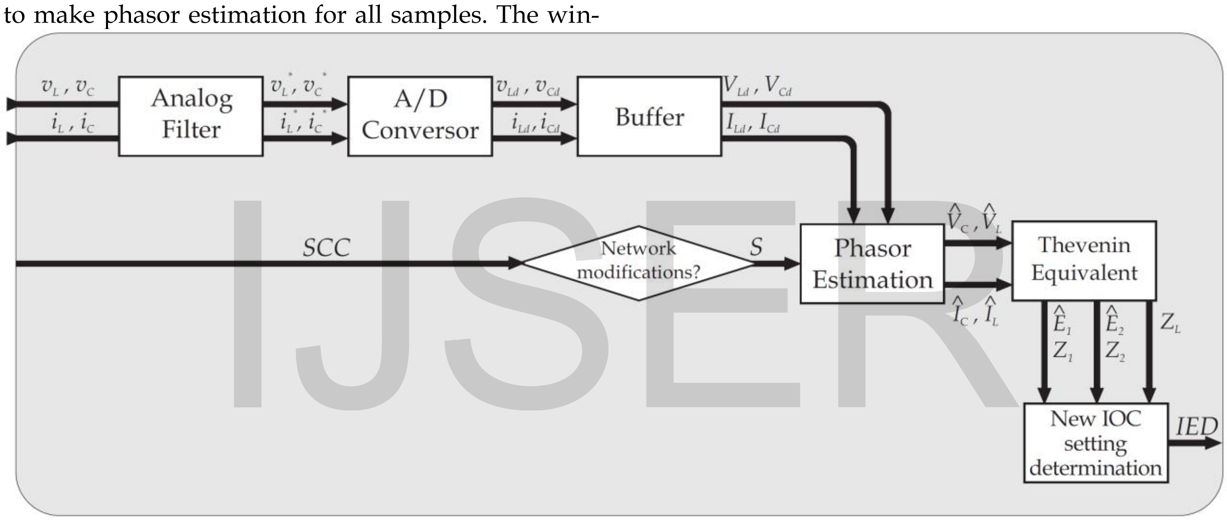


Fig. 3 - Internal architecture of Control Operational Center.

### 2.3 Inteligent Electronic Device (IED)

A lot of paper on technical literature suggests a relay model to most kind of analysis on the PES [20], [21], [27]. However, actually there is no defined model that provides the adaptive protection techniques implementation. For this reason, a new relay model it is necessary to realize adaptive tasks.All tables and figures will be processed as images. You need to embed the images in the paper itself. Please don't send the images as separate files.

In [17] a device with adaptive characteristics has been describle. However, proposed relay model needs a high processing performance, this fact makes the proposal commercially nonviable. Furthermore, the IED will concentrate all adaptive protection tasks. This fact should be strenuously avoided since the probability of failure in the system would increase rather.

So, an adaptive protective device may have, beyond the functions of any protective device, the possibility of adjustment settings change with no stop analysis of voltage and current process. Actually, most recent relay have a logic control process, that use digital switch equipments, such as circuit breakers, status to change relay adjustments settings [28]. However, to do this process an offline step is necessary.

To torn possible this characteristic, a new step was added to the basic relay model proposed in [21]. This step will be responsible to automaticlly relay setting permute.

In Fig. 4, the proposed device model was presented. As can seen in Fig. 4, on the new relay model there is a communication channel to receives adjustments settings that are provided using an online method by COC.

## 3 Description Of Methods Applied In This Work For Frequency Estimation

In this section, the description of many methods applied in this work for the fundamental frequency estimation is presented.

### 3.1 Method Based On Signal Zero-Crossings

This algorithm is based on the measurement of the time interval between two zero-crossings of the sampled signal. The

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ISSN 2229-5518

exact time of the zero-crossing is obtained by linear interpolation between two consecutive samples of different sign [13] is given by:

$$t_{zc} = \frac{t_{k-1} \times V_k - t_k \times V_{k-1}}{V_k - V_{k-1}}, \quad (1)$$

were:
*k* denotes the instant of the sample that follows the zerocrossing; and *k – 1* denotes the instant the sample before the zero crossing, $(V_k, V_{k-1})$ and $(t_k, t_{k-1})$ are the voltage and time in the instant *(k)* and *(k – 1)* respectively.

During the time interval between two zero-crossings, it is possible to assume that the frequency value is equal to the last calculated value. The frequency in the instant (k) is calculate by:

$$f_k = \frac{1}{2 \times \left(t_{zcnext} - t_{zcprevious}\right)}, \quad (2)$$

were
$f_k$ denotes the fundamental frequency, in Hz, calculated in the instant *k* by zero-crossing; $t_{zcnext}$ denotes the time of the next zero-crossing; $t_{czprevious}$ denotes the time of the previous zero-crossing.

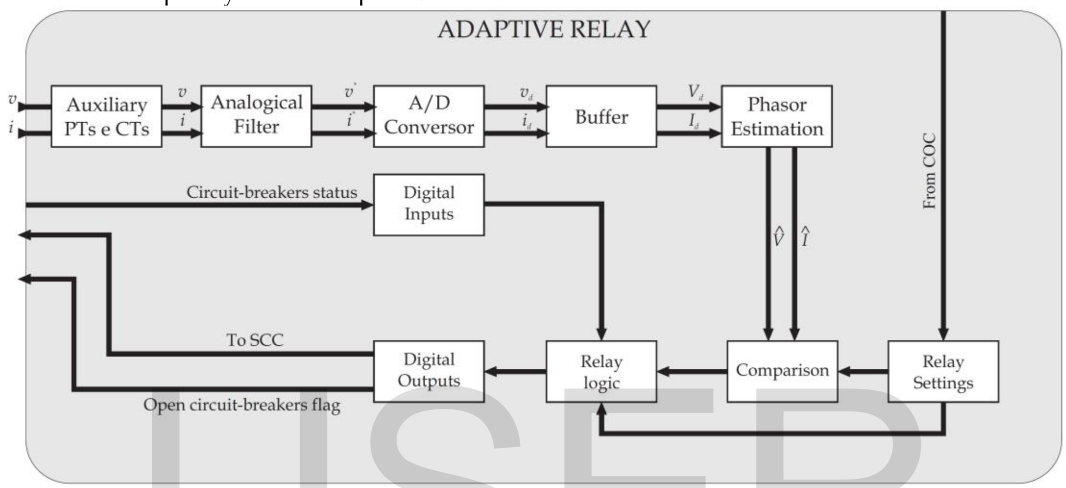


Fig 4. Adaptive relay model.



### 3.2 Adjustment of Points of Pure Sinusoidal Waveform Method

This method was applied in [13], in this method is used trigonometric relations to find the frequency value. The method based on three consecutive samples $(V_{k-2}, V_{k-1}, V_k)$, spaced by a time interval $\Delta t$, was used. In such conditions, the pure sinusoidal wave fulfils the following relationship is given by:

$$\cos(2\pi f_k \Delta t) = \frac{V_{k-2} + V_k}{2 \times V_{k-1}}. \quad (3)$$

The frequency *f*, is obtained for voltage calculated in the instant *(k)* and the time interval $\Delta t$ is given by:

$$f_k = \cos^{-1}\left(\frac{V_{k-2} + V_k}{2 \times V_{k-1}}\right) \times \frac{1}{2\pi \Delta t}. \quad (4)$$

### 3.3 Combined Frequency Estimation Technique: Hybrid Method

This method was presented by [14 –15] and combines two traditionally techniques. The method combines the zero-crossings method and the APPSW method. If *T2* is the time length of the latest tree cycles. The precision of the zero-crossings is corrupted by effect of noise and harmonics and for minimize this problem is can use the average of the frequencies of the last three cycles of the signal, given by:

$$f_2 = \frac{3}{T_2}. \quad (5)$$

The equation (5), this equation provides greater immunity to signal distortions. However, is less sensitive to frequency variations, for this reason is used f1 (frequency obtained by zero-crossing in one cycle) or f2 (frequency obtained by zero-crossing in tree cycles), given by:

$$\begin{aligned} &If \left| f_2 - f_1 \right| < Th_1, \\ &then: f_0 = f_2, \\ &else: f_0 = f_1, \end{aligned} \quad (6)$$

Where $f_0$ denotes the final value estimated by the sample count and interpolate method; and $Th_1$ denotes a threshold value equal to the maximum error due to noise and harmonic effects in (5) and the value used is 0.01 Hz [15].

The second method APPSW have the same problem that the zero-crossing. The specified conditions are as follows:

$$\begin{aligned} &If \left| \frac{fr_{k-1} + fr_{k-2} + fr_{k-3}}{3} - fr_k \right| < Th_2, \\ &Then: f_k = fr_k, \\ &else: Then: f_k = f_{0k}, \end{aligned} \quad (7)$$

Where *(k)* represents the sample number; $fr_k$ denotes the value of frequency estimated by the APPSW algorithm; $f_{0k}$ denotes the value of frequency estimated by the zero-crossing algo-

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rithm; and $f_k$ denotes the final output of the frequency estimation algorithm. Results obtained from simulation studies indicate that an appropriate value for $Th_2$ is0.05 Hz [15].

## 4 Adaptive Instantaneous Overcurrent

Instantaneous overcurrent setting is most frequently defined by pick-up current unit [28]. However, some authors have been shown that, also distance protection, instantaneous overcurrent relays may act based on local fault where short-circuit current was equal to pick-up current setting [10].

Directional instantaneous overcurrent settings [25] propose the following equation to obtain the reach of instantaneous overcurrent unit.

$$h = \frac{Z_{LT} - Z_S \times (k_1 - 1)}{k_1 \times Z_{LT}}, \tag{8}$$

Where $Z_{LT}$ is the line impedance, $Z_S$ is the equivalent impedance, and $k_1$ is the reliable coefficient.

In this paper, system equivalent impedance in an online method based on [9], was obtained. To estimate system Thevenin equivalent circuit, load voltage and current samples are required.

## 5 Case Study

To evaluate the proposed method, a real Brazilian subtransmission system was used. This system composes part of the EDAL system. The system has 11 bus and 20 lines. The total installed load has 242.6 MW and 107 MVAr. According to Fig. 5, two units of DG are connected on the grid by CPC and CZA bus. CPC and CZA generators supply about 40% of total load system.

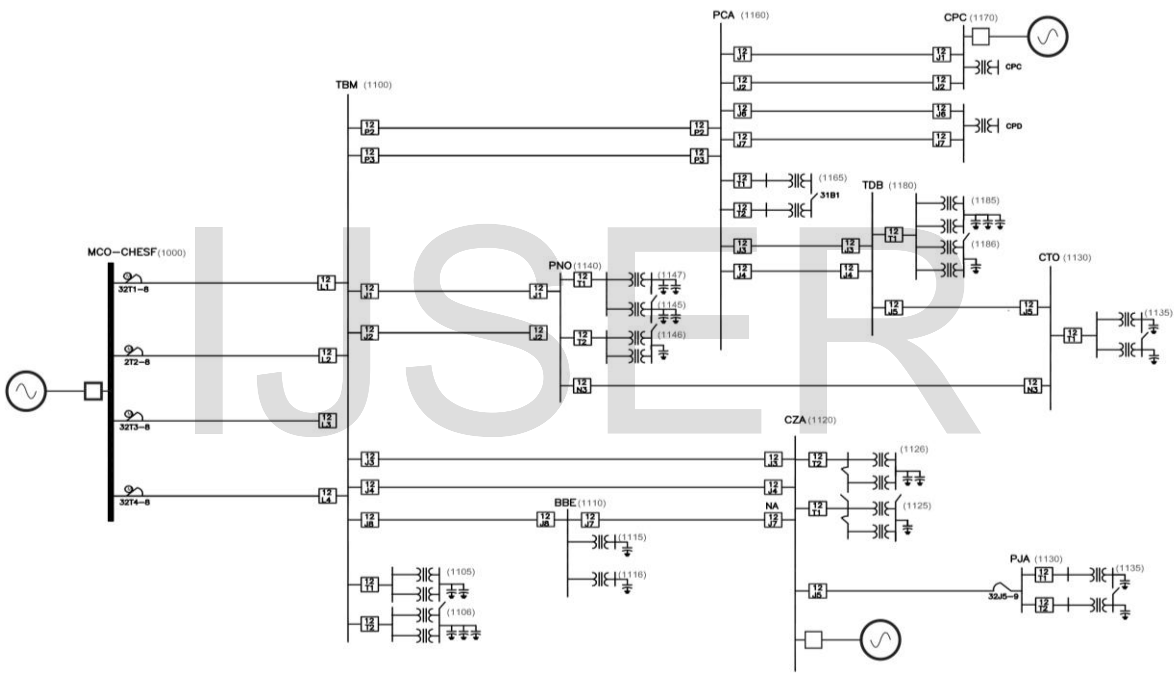


Fig. 5. Maceió region power system.



Three cases were analyzed in this paper. On the first, any generation was connected on the grid, so all installed load was supplied by the main generator. On the following cases, generators were connected to the network. In each case, a stream of three relays was coordinated using adaptive technique proposed.

Only one side instantaneous directional overcurrent unit was simulated in this paper. The relays were placed on the following lines:

- R1 - MCO-CHESF Line 1
- R2 - TBM-PNO Line 1
- R3 - PNO-CTO

The first relays (R1) may protect a line with only 500 m. On the second protective device (R2), the line protected has 10.34 km and, R3 relay acts on a line with 3.014 km.

### 5.1 Without Distributed Generation

On this case, all installed load was supplied by the main generator. As may be seen on Fig. 6, for all relays adaptive proposed method obtain feasible results for the reach of instantaneous directional overcurrent unit.

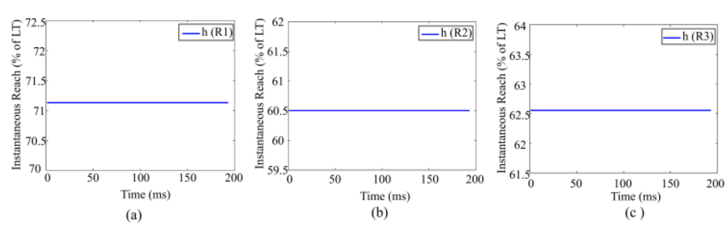


Fig. 6. Reach of instantaneous directional overcurrent unit when no distributed generator it is on the grid.

### 5.2 With CPC and CZA Distributed Generators

In this scenario, the influence of total DG was analyzed. In this cases, the contribution of power generators to fault current, make the reach of instantaneou overcurrent units of relays closer that when only main generator is connected to the grid. However, to relay R3, near CPC and CZA buses, the greater value was obtained. This occurs because the contribution of the main generator for fault near R3 is less than when no DG is connected. On Fig. 7 reach of instantaneous directional overcurrent is present with all DG are connected on the grid.

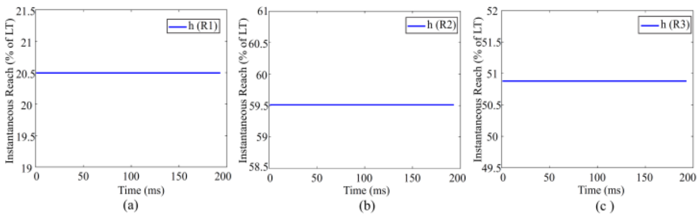


Fig. 7. Reach of instantaneous directional overcurrent unit when CPC and CZA distributed generator it is on the grid.

### 5.3 Disconnection of CPC Distributed Generator

CPC distributed generator unit supplies 60% of total GD of the system. In effect of CPC get out of the grid, the main generator increases its contribution to supply the loads. So, for relays installed near the main generator, a reduction on the reach of instantaneous directional overcurrent unit was observed. For the R3 relay, near CPC bus, was verified that a large variation on Thevenin equivalent system. In addiction to this variation, reach of overcurrent instantaneous unit was verified as can see on Fig. 8.

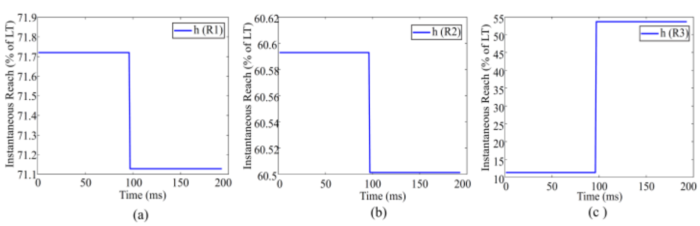


Fig. 8. Reach of instantaneous directional overcurrent unit when CPC distributed generator get out of the grid.

### 5.4 Disconnection of CZA Distributed Generator

CZA contribute with about 40% of total DG of the system. However, this generator plant is located on an important region. The effect of CZA DG may provide a change on the direction current seen by R3 relay.

Because of this characteristic a little modification in relation of CPC out of the grid, the reach of instantaneous directional overcurrent unit were observed as shown in Fig. 9.

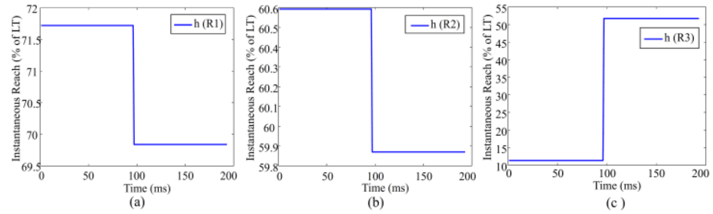


Fig. 9. Reach of instantaneous directional overcurrent unit when CZA distributed generator get out of the grid.

## 6 Conclusion

In this paper was presented an adaptive overcurrent protection technique based on monitoring of the variation of the fundamental frequency, to obtain instantaneous overcurrent unit of relays, based on frequency estimation for identifying modifications on the grid topology. The online estimation of equivalent circuit gives to the proposed technique a characteristic of really adaptive protection scheme. The results of proposed adaptive scheme, confirm that offline steps do not necessary as describle in some paper.

The use of frequency estimation as an indication of change on the network is a good option to do it. The fast result provides by this technique allow an update on instantaneous overcurrent unit with less than two samples in relation to modification act.

In addition in all analyzed cases, coordination was obtained for all relays of the grid. This fact shows that the adaptive protection is really feasible in the real system and may provide improvements in the operation of the protection power system.



## Ackowledgment

The authors of this paper thank the Coordination of Improvement of Higher Education Personnel (CAPES) and the CNPq and Federal Institute of Rio Grande do Norte (IFRN) for allowing this work.

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