GRID CODE FOR ISOLATED SYSTEMS

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***Abstract* — The aim of this study is to verify the application of an interconnected system grid code in an isolated system.**

Based on the new Portuguese transmission grid code, a comparative analysis with other grid codes and operational procedures from other European countries has been made.

The main conclusions of this analysis were applied to an isolated system, with strong incorporation of wind power.

After verifying the network contingencies and dynamic conditions, the wind farm behavior, as specified by the grid codes, and the operation procedures were assessed.

The main conclusion was that fault ride through capability is essential for the network stable operation. However, the depth and duration of the voltage dip in an isolated system should be more severe than the voltage dips specified by the grid codes issued for interconnected networks.

As for the requirement of wind generators providing reactive current during a voltage dip, it was concluded that the curve imposed by the Portuguese and Spanish grid codes is not completely obeyed. Changes can be made on the parameters of the models of the wind generators to allow a small improvement of this capability.

***Index Terms*— grid code, wind generator, fault ride through, isolated system, reactive current**

I. INTRODUCTION

By the end of the first semester 2010 [1] 3,960 MW of wind capacity were installed in Portugal. This figure represents about 21 % of the total capacity installed in the national electricity system.

The percentage of supply from wind power plants on domestic consumption has been growing in recent years, reaching an average of 18 % at the end of the first semester of 2010 (Fig. 1), attaining a daily record of 63 % in March 2010.

Produção Eólica / Consumo Total			
	1º Sem 2010	2009	2008
[GWh]			
Consumo SEN	25 971	49 872	50 595
Produção Eólica	**4 740**	**7 492**	**5 695**
	18%	15%	11%

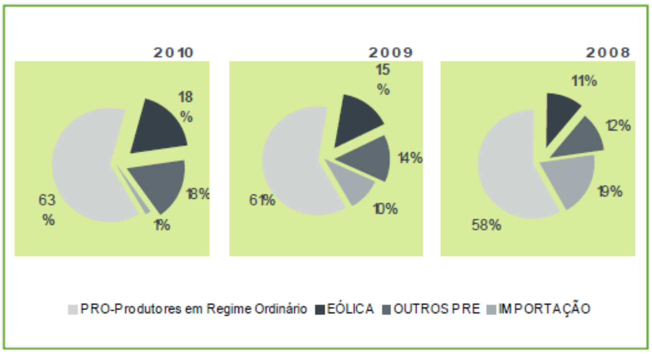


Fig. 1– Percentage of supply from wind power plants to satisfy domestic consumption

Given the values of wind power capacity already installed and the volatility of wind power production (Fig. 2), the integration and the loss of substantial amounts of wind generation in the grid begin to have a significant impact on the network security and on the supply quality.

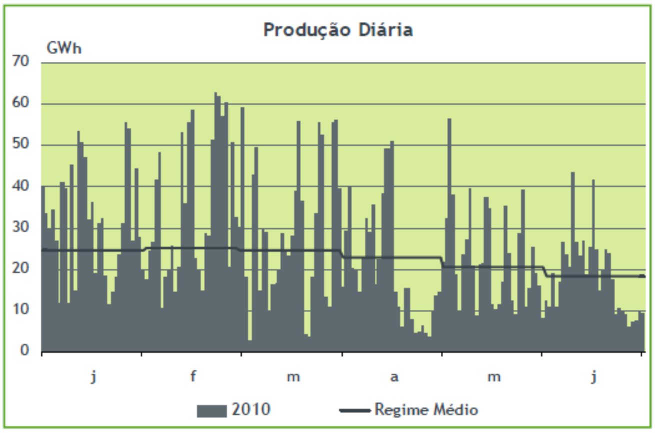


Fig. 2– Volatility of wind power plants

However, it is expected that wind power capacity continues to grow all over the world with the installation of new wind farms and/or the expansion of wind farms already in operation. Given this reality, some European countries such as Spain, Ireland and Germany have already specified guidelines for the connection of renewable energy power plants (particularly wind power plants) with even more challenging new rules.

In Portugal, the new Transmission and Distribution grid codes were recently approved. The technical conditions for the connection of wind power plants to the grid are introduced in these codes.

However, these grid codes are not applied to the Portuguese islands: Madeira and Azores. Madeira and Azores have specific network procedures that define the access and operation condition adapted to their reality, but these procedures do not include the connection of wind power plants.

II. Comparative analysis of several grid codes

The new Portuguese transmission grid code (RRT) [2] was taken as an example of an interconnected grid code. This document was compared with other grid codes and procedures, such as: the Madeira island network procedures (Manual do SEPM) [3] (Madeira electrical network was used as an example of an isolated system); the Spanish operating procedures (P.O. of REE) [4], [5] and [6]; the operating procedures of small systems and electrical systems isolated in Spain, called SEIE (P.O. of SEIE) [7]; and an appendix of the Irish grid code that establishes the technical rules which wind farms must comply with, regarding their connection and operation on the transmission system (WF1/WFPS1) [8].

A. *Single contingencies [N-1]*

A failure that occurs in a single network element (such as a generator, a line, an auto-transformer, a transformer or a capacitor) is called a single contingency or [N-1].

Considering single contingencies, TABLE I(A) shows the voltage and frequency limits established on each grid code studied. The allowed rate for temporarily overloads occurring in lines and transformers can be seen in TABLE I(B):

TABLE I(A)
Contingencies [N-1]

Grid Code	**Voltage (p.u)**	**Frequency (Hz)**
Portugal: RRT	400 kV: 0,93 – 1,05 220 kV: 0,93 – 1,11 150 kV: 0,93 – 1,10 63 kV: 0,95 – 1,05	49,5 – 50,5
Madeira Island: Manual do SEPM	0,90 – 1,10	49,5 – 50,5
Spain: P.O.1.1. REE	400 kV: 0,95 – 1,09 220 kV: 0,93 – 1,11	49,85 - 50,15
SEIE: P.O.1.	220 kV: 0,93 – 1,11 132 kV: 0,93 – 1,10 66 kV: 0,91 – 1,09	49,85 - 50,15 for t<5min: 49,75 – 50,25
Ireland: WF1/WFPS1	400 kV: 0,88 – 1,05 220 kV: 0,91 – 1,11 110 kV: 0,90 – 1,12	Not been studied

TABLE I(B)
Contingency [N-1]

Grid Code	**Lines overloads (%)**	**Transformers overloads (%)**	
Portugal: RRT	t<20min winter: 15 intermediate:15 summer: 15	t<20min winter: 25 intermediate:15 summer: 10	20min<t<2h winter: 20 intermediate: 10 summer: 5
Madeira Island: Manual do SEPM	t<20min: 20 t<10min: 30	t<2h winter: 20 summer: 10	
Spain: P.O.1.1. REE	t<20min: 15	winter: 10	
SEIE: P.O.1.	t<20min: 15	t<20min winter: 25 intermediate: 20 summer: 15	20min<t<8h winter: 15 intermediate: 10 summer: 5
Ireland: WF1/WFPS1	Not been studied		

Double contingencies [N-2] and/or extreme contingencies

These contingencies are not generically defined. Each grid code specifies them as contingencies [N-2] and/or extreme contingencies.

Considering the isolated systems of Madeira and the SEIE, contingencies [N-2] occur when (a) there is a loss of a double circuit line and extreme contingencies occur when (b) it is lost the largest generator in service.

Considering these contingencies, TABLE II(A) shows the voltage and frequency limits established on each grid code studied and TABLE II(B) details the allowed temporary overloads for lines and transformers :

TABLE II(A)
Contingency [N-2] and/or extreme contingencies

Grid Code	**Voltage (p.u)**	**Frequency (Hz)**
Portugal: RRT	400 kV: 0,90 – 1,05 220 kV: 0,90 – 1,11 150 kV: 0,90 – 1,10 63 kV: 0,94 – 1,05	49,5 – 50,5
Madeira Island: Manual do SEPM	0,90 – 1,10	49,5 – 50,5
Spain: P.O.1.1. REE	400 kV: 0,94 – 1,09 220 kV: 0,91 – 1,11	49,85 - 50,15
SEIE: P.O.1.	220 kV: 0,91 – 1,11 132 kV: 0,90 – 1,10 66 kV: 0,85 – 1,09	49,85 - 50,15 for t<5min: 49,75 – 50,25
Ireland: WF1/WFPS1	400 kV: 0,88 – 1,05 220 kV: 0,91 – 1,11 110 kV: 0,90 – 1,12	Not been studied

TABLE I(B)
Contingency [N-2] and/or extreme contingencies

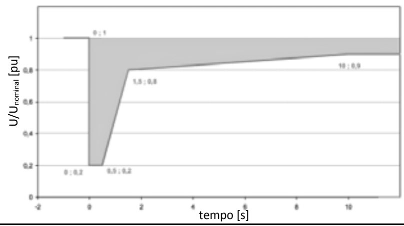
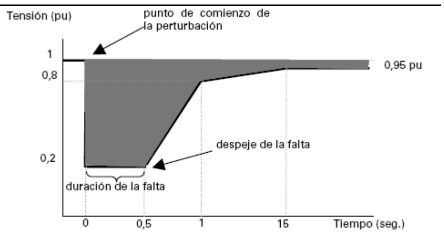
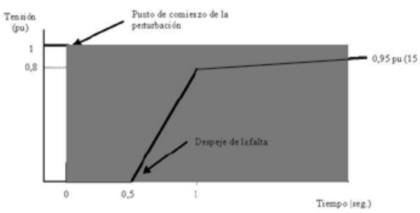
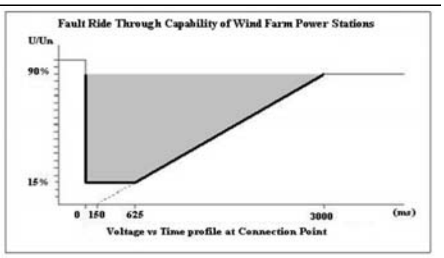
Grid Code	**Lines overloads (%)**	**Transformers overloads (%)**	
Portugal: RRT	t<20min winter: 15 intermediate: 15 summer: 15	t<20min winter: 25 intermediate:15 summer: 10	20min<t<2h winter: 20 intermediate:10 summer: 5
Madeira Island: Manual do SEPM	(a)t<20min: 30 (b)t<20min: 20 (b)t<10min: 30	t<2h (a)winter: 30 (a)summer: 10	t<2h (b)winter: 20 (b)summer: 10

Grid Code (cont.)	Lines overloads (%)	Transformers overloads (%)	
Spain: P.O.1.1. REE	15	winter: 20 intermediate:15 summer: 10	
SEIE: P.O.1.	t<20min: 15	t<20min winter: 25 intermediate:20 summer: 15	20min<t<8h winter: 15 intermediate:10 summer: 5
Ireland: WF1/WFPS1	Not been studied		

B. *Wind farm requirement: fault ride through capability*

The wind turbine generators must remain connected to the grid for voltage dips on any or all the phases when the voltage measured at the high voltage terminals of the grid connected transformer remain above the heavy black line shown in TABLE III, for each grid code:

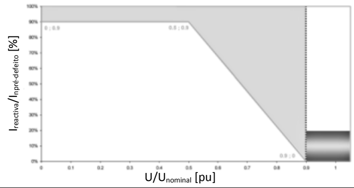
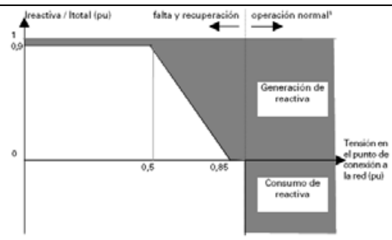
TABLE III
FAULT RIDE THROUGH REQUIREMENT

Grid Code	Fault ride through requirement
Portugal: RRT	
Madeira Island: Manual do SEPM	Not defined
Spain: P.O.12.3. REE	
SEIE (Canaries): P.O.12.2.	
Ireland: WF1/WFPS1	

C. *Wind farm requirement: provide reactive current during a fault*

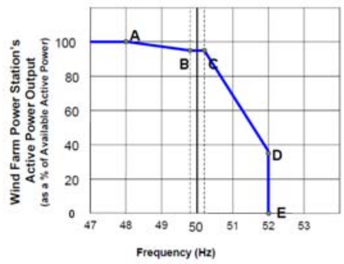
During a voltage dip, the wind generators must supply the network with reactive current in order to provide voltage support. This requirement is specified only in the Portuguese and Spanish grid codes, as shown on TABLE IV:

TABLE IV
REACTIVE CURRENT CONTRIBUTION

Grid Code	Reactive current contribution
Portugal: RRT	
Madeira Island: Manual do SEPM	Not defined
Spain: P.O.12.3. REE	
SEIE: P.O.12.2.	Not defined
Ireland: WF1/WFPS1	Not defined

D. *Frequency response*

TABLE V
FREQUENCY RESPONSE

Grid Code	Frequency response
Portugal: RRT	Portuguese grid code doesn't specify a frequency response system. However, wind generators should remain connected to the grid, for frequency ranges between 47,5 Hz and 51,5 Hz
Madeira Island: Manual do SEPM	Not defined
Spain: P.O. REE	-
SEIE (Canaries): P.O.	-
Ireland: WF1/WFPS1	

In Ireland, a wind farm must comply with a frequency response system set by the curve of the TABLE V. Under normal frequency ranges, the wind farm shall operate with active power output as set by line B-C. If system frequency falls below point B, then the frequency response system shall act to ramp up the wind farm's active power output, in accordance with the frequency/active power characteristic defined by the line B-A.

III. Application to an Isolated System

The isolated system used in these study simulations was the electrical network of Madeira Island. This network was created in a study [9], presented by the *Centro de Energia Eléctrica* from *Instituto Superior Técnico (IST-CEEL)* and *Rede Eléctrica Nacional, SA (REN)*, in March 2009.

On this network a strong incorporation of wind generation in the generation mix was considered and two load scenarios were studied: peak summer load (PV) and valley winter load (VIT).

A. Single contingencies [N-1]

With the occurrence of a single fault in PV scenario, there were some situations where the voltage dropped below the lower limit defined in RRT (0,95 p.u.) and the lower limit of the islands (0,90 p.u.), as shown on Fig. 3.

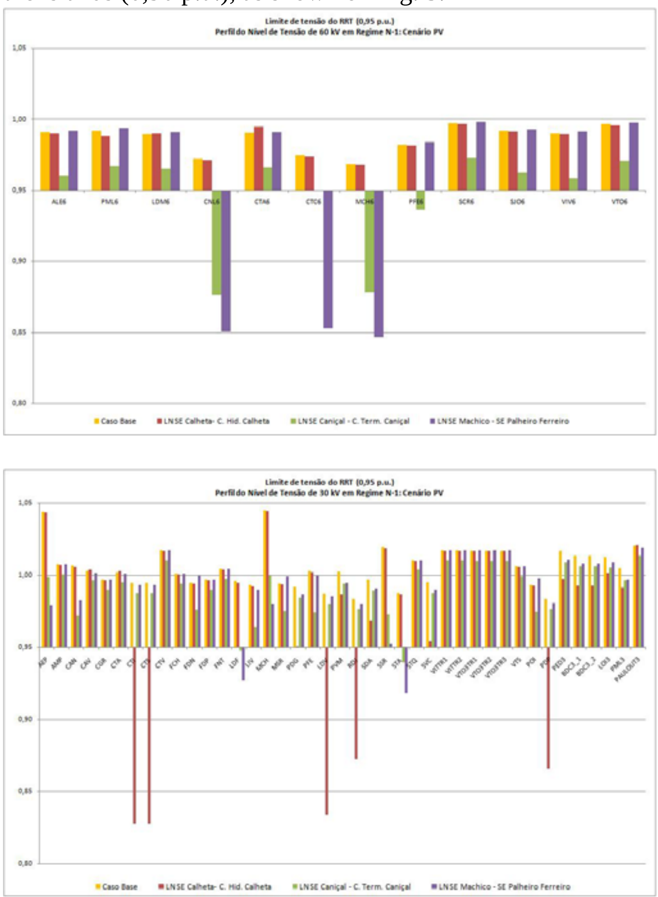


Fig.3 – Voltage profile on PV scenario: (a) on the 60 kV buses; (b) on the 30 kV buses

In the VIT scenario, the voltage profile is higher, so only some out of limits voltage situations occurred on the 30 kV buses.

Only some of the parallel branch (line or transformer) were in overload. This overload occurs when there is a fault in one of the parallel branches (the faulted branch is disconnected) and the other parallel branch stays overloaded.

B. Double contingencies [N-2] and/or extreme contingencies

Only some of the 30 kV buses have the voltage higher than the upper limits defined in the RRT (1,05 p.u.) and it only occurs on the VIT scenario.

With the occurrence of simultaneous faults on double circuits there were some lines overloaded (on the PV scenario)

C. Transient Stability

For the transient stability study, a symmetrical three-phase fault was applied in each terminal bus of all the branches of the transmission network of Madeira Island. It was assumed that fault was cleared in 250 ms with the opening of the faulted branch.

Certain areas of Madeira transmission system possess a radial configuration, which implies that the occurrence of a fault causes the formation of isolated systems. In these areas, the voltage reaches values outside the limits imposed by the grid code and there are some branches in overload.

Checking the voltage limits

Considering the voltage range of ± 10 %, set in the islands grid codes (Madeira and Ireland), there are no situations of limits breach, except when the formation of isolated system occurs.

However, if one considers the range of ± 5 % of the RRT, there are some situations where the voltage reaches values outside the established limits. Those situations occur when the fault is near the power station which supplies about 25 % of the reactive power required by the network.

Checking frequency deviations

During the transient stability simulations five strategic buses were monitored allowing the identification of network separation and/or unstable situations.

In some situations transient fluctuations of the frequency occurred immediately after the fault and exceeded the limits established on the RRT (49,5 Hz and 50,5 Hz). However, there were no cases of network instability and the frequency stabilized in the acceptable range before the end of the simulation time, as shown in Fig. 4

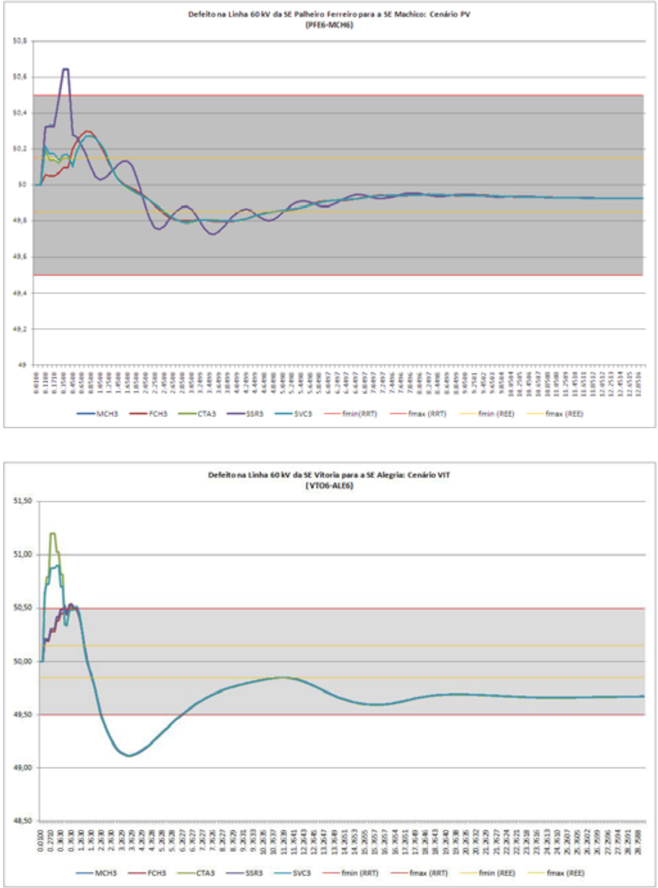


Fig. 4 – Frequency evolution considering (a) a fault in the PV scenario and (b) a fault in the VIT scenario

Checking lines and transformers overloads

There were no cases of overloads on lines or transformers, apart from occasional overloads in some of parallel branches.

Checking wind farm requirement: fault ride through capability

There are two types of wind generators connected in Madeira Island. The more recent wind generators are capable of fault ride through during voltage dips: these wind generators are of the Double Fed Induction Generator (MIDA) type. The first wind generators installed in Madeira don't' have the fault ride through capability and are of the Squirrel Cage Induction Generator (MIRG) type.

To satisfy the RRT curve of fault ride through, under voltage protections of the MIDA wind generators have to be parameterized according to Fig. 5.

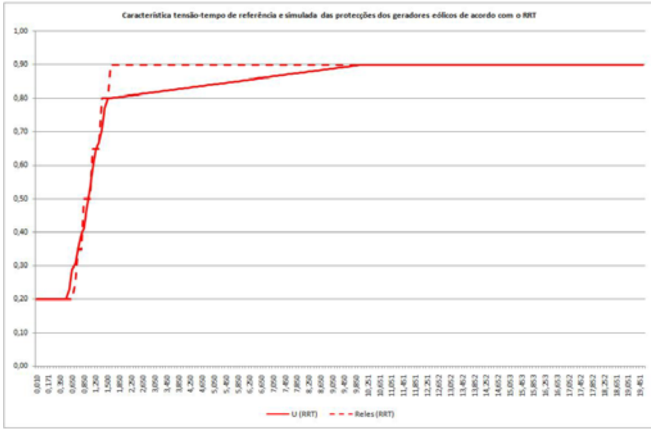


Fig. 5- Voltage reference and simulated of the protections of MIDA according to RRT

In all simulations, MIDA wind generators remained connected, except in situations where the fault occurred nearby the grid substations that collects wind farm production.

When voltage wind generators drops below 0,2 p.u., these generators were disconnected from the network, according to the parameterization of the under voltage protections (as shown in Fig. 6).

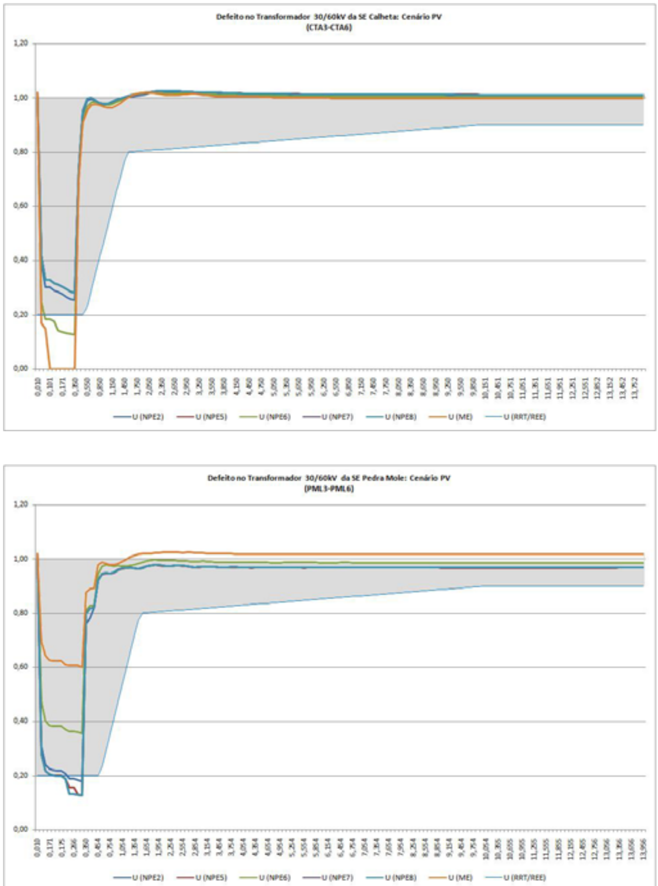


Fig. 6– Examples of voltage dips that cause the disconnect of wind generators

Checking wind farm requirement: provide reactive current during a fault

In all simulations, wind generators do not fully follow the supply curve of reactive current, required on RRT, as we can see in the examples shown in Fig. 7.

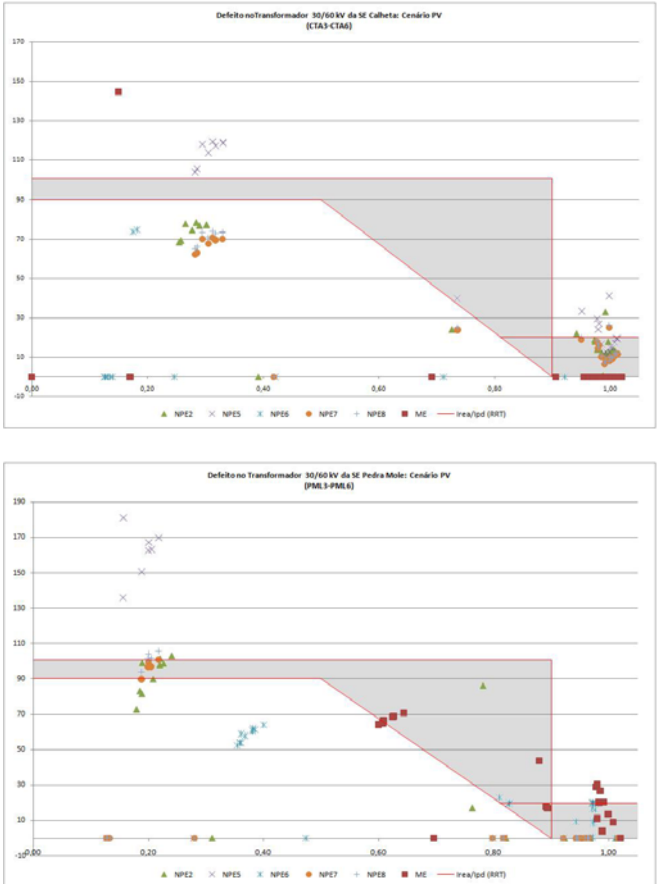


Fig. 7– Check the supply curve of reactive current during the faults of Fig. 6

IV. Changing parameters: compliance with the injection of reactive current curve during voltage dips

Trying to comply with the curve of RRT for the supply of reactive current during voltage dips, it was attempted to change the values of I_{rea}/I_{pd}.

The pre-fault current (I_{pd}) is the current injected by the wind generator immediately before the occurrence of the fault (t = 0 s). Since I_{pd} is a constant value, I_{rea}/I_{pd} can only be changed by modifying the reactive current (I_{rea}). In this model, I_{rea} can be modified by changing the value of equivalent reactance (X_{eq}). Typically X_{eq} is equal to 0,8.

As an experience, the value of X_{eq} was changed in all of the wind turbines in one of the wind farms. As can be seen in Fig. 8 both the sensitivity of wind generator to voltage dip and the I_{rea}/I_{pd} distribution varies.

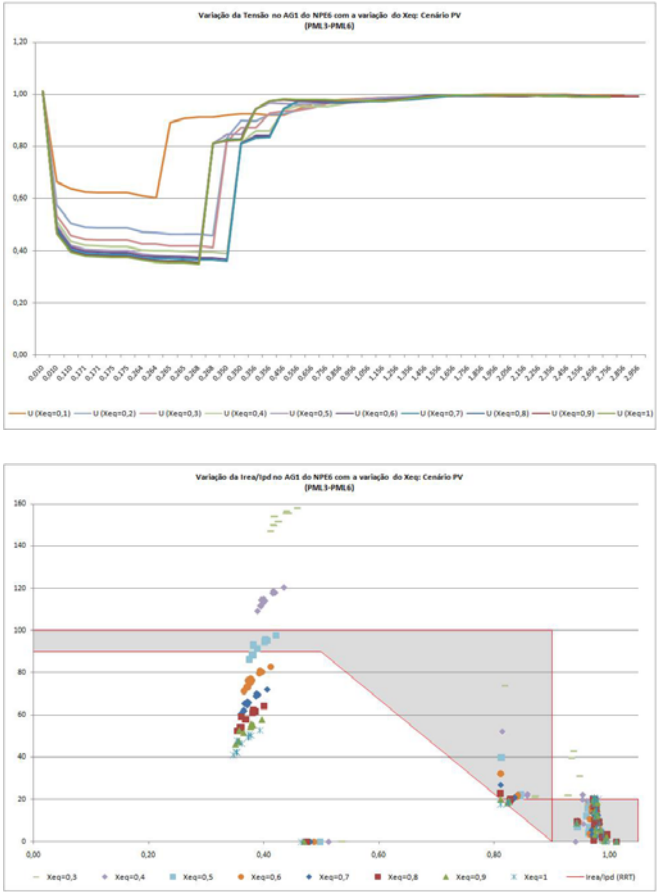


Fig. 8– X_{eq} variation: (a) voltage dips in the wind generator and (b) I_{rea}/I_{pd} distribution

V. Changing parameters: imposing a more demanding curve of voltage dips

Taking as reference the curve of the voltage dip required in Canaries [7], the parameterizations of the under voltage protections of MIDA wind generators were changed, to enforce them to comply the curve of the voltage dip of Fig. 9.

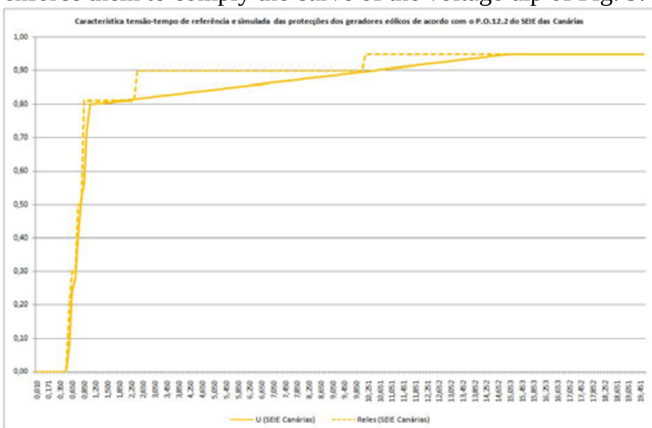


Fig. 9 - Voltage reference and simulated of the protections of MIDA according to SEIE (Canaries)

With this new parameterization, more wind farms remained connected to the network, avoiding the spread of the fault and slightly increasing the voltage at the buses affected by the fault.

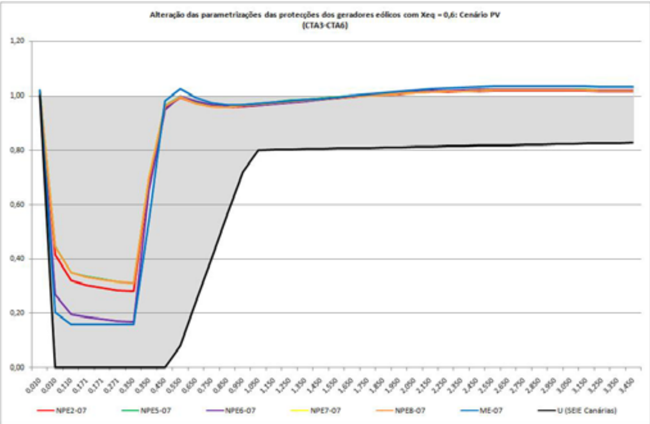
VI. Conclusion

With the analysis of grid codes and operation procedures and its implementation on an isolated grid, is clear that the limits as defined in the procedures of the islands are more favorable than those created for interconnected networks grid codes (and operation procedures).

The incorporation of wind power plants in isolated systems can be difficult, given its intermittent nature and not being dispatchable. However, the adequacy of grid codes and operation procedures to this reality, as well as the technical adaptation of wind generators, can be a challenge.

In this study it was found out that, even though there are some limitations in the wind generators model, some improvements were achieved by altering two parameters of MIDA machines: with most favorable value of X_{eq} and most demanding protections parameterizations, all the wind generators remained connected to the network during the occurrence of a fault and even the I_{rea}/I_{pd} dispersion can be improved (see Fig 10).

With these changes, the other study control parameters of the network (frequency and overload in lines and transformers) showed better performances.



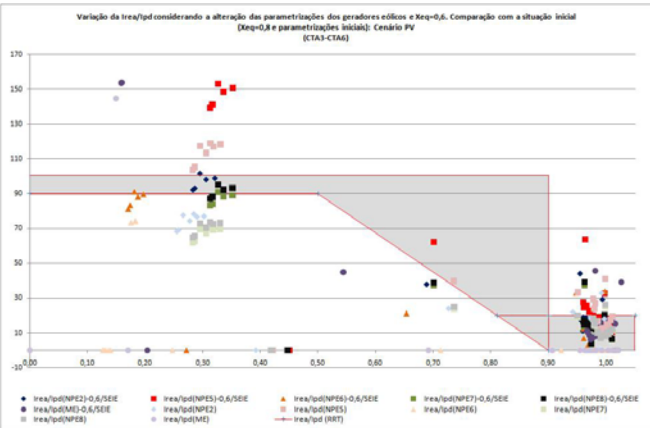


Fig. 10– (a) Voltage dip curve and (b) I_{rea}/I_{pd} distribution

Acknowledgment

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