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Analysis and computer modelling of a Rate of Change of Frequency Relay for islanding detection in the software ATPDraw

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Abstract. Although the distributed generation is bringing many benefits to the grid, its operation is also getting even more complicated due to the many loads and generators involved into it. One important issue that must be detected as fast as possible to avoid any damage for the grid and/or the loads connected is the islanding. The paper analyses the modelling of a relay based in a passive method of islanding detection for the software ATPDraw, which is current unavailable. So we focussed in a model based in the frequency, which the rate of change of frequency relay - ROCOF - was chosen. The results show that the relay was successful to detect the islanding under various circumstances and is obeying the requisites established by the IEEE 1547.

Key words

Rate of Change of Frequency, ROCOF, Islanding Detection, Islanding and Distributed Generation.

1. Introduction

A. *Distributed Generation*

Recently the Brazilian and worldwide electrical power system have gone through many changes due to the increasing demand of electricity caused by the population growth and habit changes. In a way to supply this growth in demand, the researches in renewable sources of energy, such as solar, wind, and biomass, is increasing. In Brazil, one of the most expressive sources of renewable energy is biomass, from the burn of sugarcane bagasse by the sugarcane industry.

However, lots of these generators have to be connected to the electrical distribution systems, nearby the consumption centres. Thus, they are named distributed generation because in the contrast of having a huge hydroelectric power plant with hundreds of kilometres of transmission lines far from the costumers, there are many small generators close to them.

If the distributed generation is implemented correctly, it can bring many benefits to the electrical system as reliability increase, and loses decrease. However, the distributed also inserted a higher complexity to the system, for operate as well as to design. Then, a problematic that stand out in the islanding [1].

B. *Islanding*

Islanding can be defined as the condition where part of the distribution grid stills energized even though it has been isolate from the rest of the electrical system. The islanding can be caused by various incidents in the system, such as the trip of a circuit break in a short circuit, or even by a partial shutdown of the grid by the power utility for maintenance purposes in a certain area.

Islanding might be classified in two basic types: intentional and non-intentional. In the intentional islanding, after the island has been formed the generators of the Independent Power Producer- IPP keep feeding the utility loads that are connected in the bus bars near it. However, for safety reasons of the maintenance crews, and also to avoid damage for the loads islanded with the IPP, the generator must be disconnected, since in many situations the IPP`s machines do not have the capability to supply the total demand of power required, nor conditions to ensure the power quality to the loads. Due to the overload in the generator, it will have the tendency to slow down making that some power quality parameters are unaccomplished, such as frequency and voltage, which can damage both the generator and the loads connected to it.

For the intentional islanding, this continuity to supply energy is desired, for example, to mitigate the effects caused by power outages on primary loads, as hospitals and big industries, where this can cause a great charge or is something to be avoided at most. In this situation, the generators still connected providing energy for the loads in the island uninterruptedly. Nevertheless, for a situation of intentional islanding the generator must be able to feed all the loads in the island, present a stable operation and guarantee that all the power quality parameters practiced by the utility and present in the national technical standards. Hence, it is clear the necessity of a mechanism capable of identify that an islanding had occurred during system operation to ensure the excellence and reliability of the distribution energy services.

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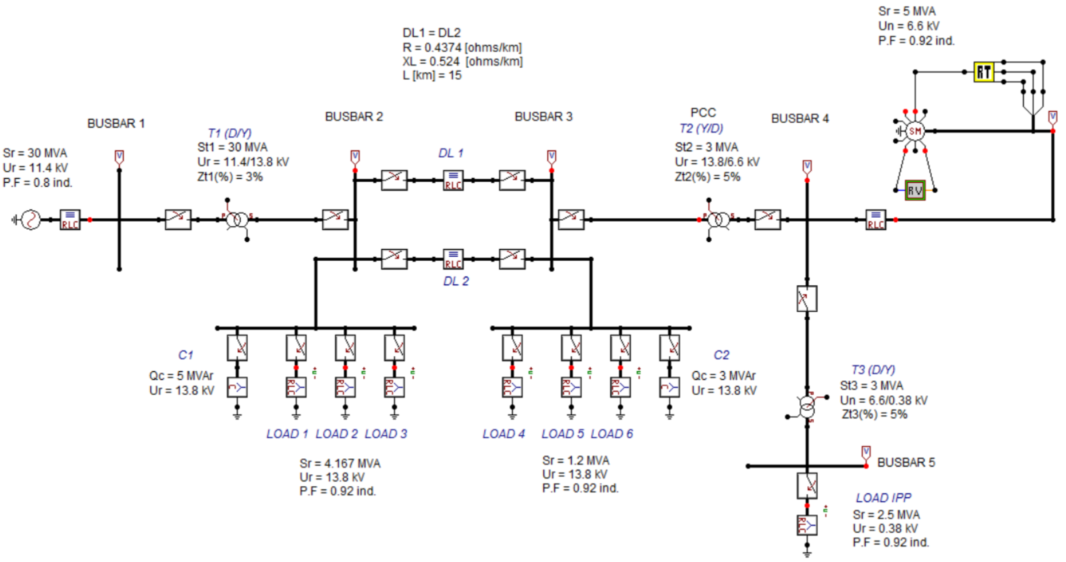


Fig.1. Schematic of the electrical system in the ATP software

C. *Islanding Detection*

The islanding detection must be done as fast as possible, in a way to avoid potential damages of system's functionality. This detection may be done through three commonly used methods, which are techniques based in communication, active, and passive parameters. Despite the technique used for this detection, according to the IEEE standard 1547, the islanding must be detected in less than 2 seconds.

In the islanding detection using the technique based in communication [2,3] a data acquisition is performed between the relays in the system in order to detect if some circuit break in the system is opened, creating an islanded system. However, this method depends of the utility infrastructure to be implemented, which makes it very complicated and expensive.

For active islanding detection, a signal is injected into the grid, and based on its behaviour you can detect if an islanding occurred or not. According to the bibliography, these methods are very effective when compared to passive ones, presenting elevate rates of success in a real event, thus both its computational and physical implementations are complex and costly.

To detect islanding passively, some electrical variables, such as voltage, current, and frequency, are utilised to analyse a possible islanding in the system. Passive methods are cheaper to install in the system, and present satisfactory results. However, since they dependent of variables in the system to detect islanding, in situations where the power generated by the IPP's machine and the power demand from the loads are very close is possible to happen a failure to detect this islanded operation, which is also known as blind of detection. Nevertheless, according to [4] this can be mitigated by using a hybrid relay capable to analyse more than one parameter with the aim of increase its precision. Additionally, [5] purpose the use of neural networks techniques to analyse the transitory in the system to achieve a higher rate of success.

Referring to the rate of change of frequency relay it is not different, once the change of frequency is associated to the change of power in the system. So, front a slightly unbalance between the generated and consumed power, it is going to have a tiny change of frequency. This fact can originate the non-detection of the islanded condition.

With the intention of evaluate the detection time of the islanding to different values of rate of change of frequency and power generated, on this study was choose and modelled the rate of change of frequency relay due to its high rate of successful detection and easy computational implementation.

2. System modelling

To represent the electrical system in the software ATP it was necessary to model all components of the system, as detailed below.

A. *Electrical System*

The electrical system used for modelling and testing for the relay is composed by one distribution system connected to an IPP, each one with its own loads, interconnected by two distribution lines.

In the IPP's electrical system there is a synchronous generator, steam turbine, with rated power of 5MVA. However, for the studies performed the generator does not provide its rated power. The simulations were directed in order to verify the impact of different levels of overload in the generator and its relation to the islanding detection time for different values of rate of change of frequency.

The data for the devices in the electrical system used here can be seen in Figure 1. The additional modelling procedures for the system were developed in according to the methods appointed in [6].

B. *Modelling of ROCOF*

The first step for modelling the ROCOF was to select a method for acquire the frequency from the system, among the two distinct ways to do it: 1) calculating the frequency of the system through the zero crossing time from the current in a busbar near the generator; or 2) using the internal variable of the synchronous machine in the ATPDraw that saves in real time, during simulation, the machine angular speed in rad/s.

In the first one, we have the option to choose how much crossing points we want to use to measure the frequency. By choosing only two consecutive crosses, the minimum amount of crosses to detect the frequency, it would require a time $t=8.33\ ms$, i.e. this is the time necessary to have a new value for the frequency to use as the input into the relay. This method to determinate the frequency was studied to model the rate of change of frequency relay by [1], [7]-[11].

Using the machine angular speed, from the internal variable on ATPDraw, the time necessary to obtain a new value of frequency drops drastically, being more than 800 times smaller than the previous method, as the time step used was 0.00001 seconds.

After this, the method used on this study was to utilize the machine internal speed to indirect calculates the electrical frequency of the system.

In order to get the electrical frequency of the IPP's generator in Hertz, it is necessary to make some conversions. These conversions depend only of the generator angular speed and its quantity of poles.

$$\omega_e = \omega_m \cdot \frac{poles}{2} \qquad [rad/s] \qquad (1)$$

$$f_e = \frac{\omega_e}{2\pi} \qquad [Hz] \qquad (2)$$

After obtain the electrical frequency from the grid, we calculate the value rate of change of frequency, which will be compared with the relay parameter that refer to the maximum change allowed in the system. Showed below is the basic structure of the rate of change of frequency relay - ROCOF, as it is usually used, the only difference is in the fact of the input be the angular speed and not the frequency of the grid.

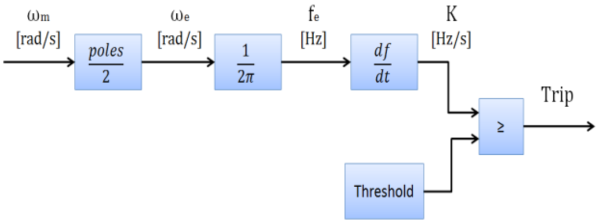


Fig.2. ROCOF schematic diagram

In the model of the ROCOF implemented on ATPDraw were done some changes as the use of low pass filters and the implementation of a voltage blockage, which is the minimum voltage that must have in the grid to allow the relay to trip. This way, the voltage blockage can help to prevent a false trip, for example, caused by voltage sag.

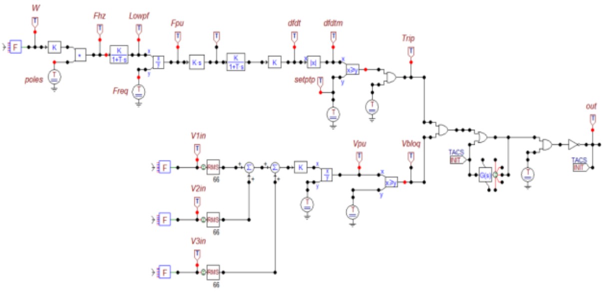


Fig.3. Schematic diagram of ROCOF on ATPDraw

After the validation tests, all the blocks that are part of the ROCOF structure were reduced to a single visual block with the purpose to ease the usage of this relay in simulations. On Figures 4 and 5 are illustrated the final results of the relay modelling and its parameters of configuration, respectively. According to the picture below the relay pins are: 1) speed input; 2) trip signal output; and 3) three phase voltage input.

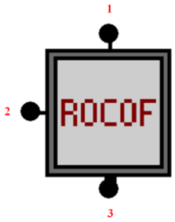
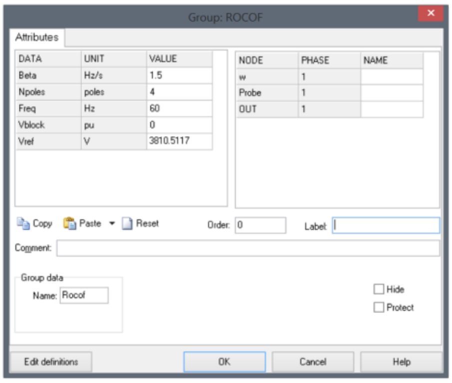


Fig.4. ROCOF final block on ATPDraw



DATA	UNIT	VALUE
Beta	Hz/s	1.5
Npoles	poles	4
Freq	Hz	60
Vblock	pu	0
Vref	V	3810.5117

NODE	PHASE	NAME
w	1	
Probe	1	
OUT	1	

Order: 0

Label:

Comment:

Group data

Name: Rocof

☐ Hide

☐ Protect

Fig.5. ROCOF internal parameters window

3. Case Studies

In order to validate the relay model developed, different tests were conducted for an islanding situation by the disconnection of the two distribution lines with the busbar 3, Figure 1. In the tests the generator was set to generate two distinct values of power, 3MVA and 4MVA. These values of power generated by the IPP machine was combined with 3 stages of loads with the purpose of obtain various values of overload to the islanded system.

For each of the cases, were used three different values of rate of change of frequency as the parameter for the relay, to verify how it affects the islanding detection time.

A. 3MVA Generation

After the correct setup the generator to generate 3MVA of power, was made a trip study of the relay forcing an islanding conditions in the system in t=3 seconds after the simulation had started. On Table I are presented the active and reactive power generated by the synchronous machine of the IPP, and Table II shows the detection time for each of the case studies.

Table I. – Power generated by de DG

S	P	Q
3 MVA	2.78 MW	1.1 MVAr

Table II. – Detection times for each case study

Case Studies	Generation [MVA]	β [Hz/s]	Load [MVA]	Detection time [ms]
1	3.0	0.5	3.7	5.0
2			4.9	3.8
3			6.1	3.4
4		1.5	3.7	5.4
5			4.9	5.0
6			6.1	4.5
7		2.5	3.7	5.8
8			4.9	5.4
9			6.1	5.1

According to the IEEE standard 1547 the islanding detection must be done in less than 2 seconds, and by the obtained results, for all the nine case studies with the generator generating 3MVA, the relay was capable to identify the islanding in a time much smaller than what the standard requires.

In Figure 6 is presented in red the rate of change of frequency after the islanding happens in $t = 3s$. due to the overload in the generator, the frequency begins to drop, and when the rate of change of change of frequency goes over the value β = 1.5 Hz/s, the signal trip, in magenta, changes from 1 to 0, in order to open the circuit break that connects the generation system with the distribution system, allowing the generator to supply energy just to its internal loads.

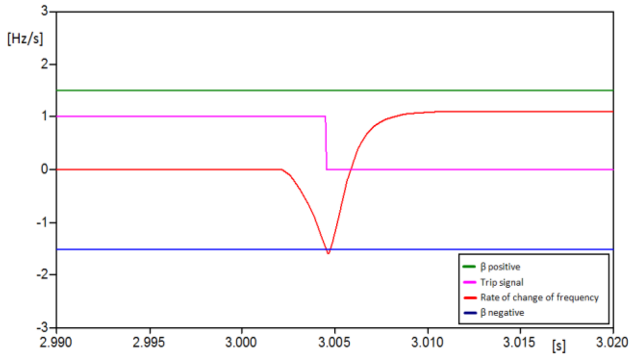


Fig.6. Detection of case study 6 generating 3MVA

As the internal loads correspond to 2.5 MVA the frequency of the islanded system increase again and lately stabilise in a value above 60 Hz. For these cases where the power generated by the generator was about 60% of its rated power, some oscillations in the power angle of the generator can be noticed, since the power angle was 33° due to the power the generator was operating and after the islanding detection the generator passes to operate in a new power angle of 27.6°, Figure 8.

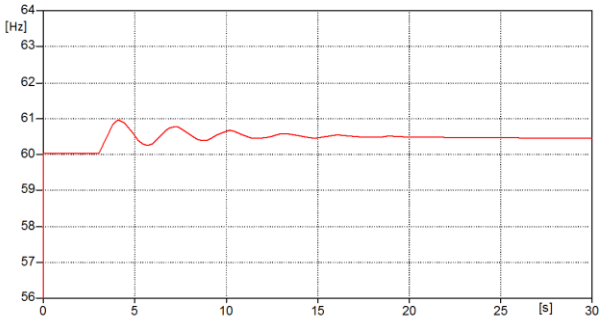


Fig.7. Frequency of case study 6 generating 3MVA

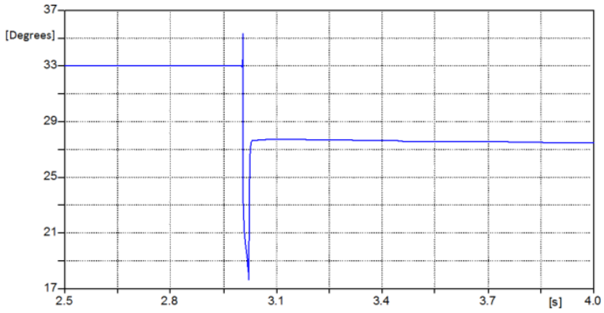


Fig.8. Power angle of case study 6 generating 3MVA

B. *4MVA Generation*

In this case, the generator was set to generate 4 MVA of power. Once again, in t = 3s an islanding was forced to evaluate the relay's operation. On Table III are presented the active and reactive power generated by the synchronous machine of the IPP, and Table IV shows the detection time for each of the case studies.

Table III. – Power generated by de DG

S	P	Q
4 MVA	3.68 MW	1.54 MVAr

Table IV. – Detection times for each case study

Case Studies	Generation [MVA]	β [Hz/s]	Load [MVA]	Detection time [ms]
1	4.0	0.5	3.7	4.5
2			4.9	4.9
3			6.1	4.4
4		1.5	3.7	5.2
5			4.9	4.7
6			6.1	4.3
7		2.5	3.7	5.6
8			4.9	5.2
9			6.1	4.8

For this case we can notice that the relay also presented 100% of successful islanding detection, and the detection time kept way below the value of 2 seconds stated by the IEEE standard 1547.

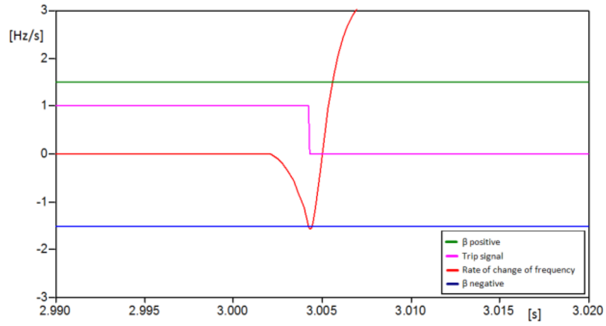


Fig.9. Detection of case study 6 generating 4MVA

Similar of what was presented for the case where the generator was producing 3MVA, the relay signal trip, in magenta, goes from 1 to 0 when the value of rate of change of frequency exceed the value of the parameter β, 1.5 Hz/s, Figure 9. Furthermore, as a result of the internal load of the generator is much smaller than the power generated it, the frequency elevates and stabilizes in a new value over 60Hz, Figure 10.

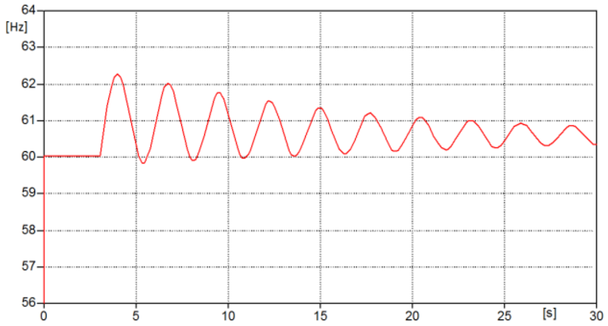


Fig.10. Frequency of case study 6 generating 4MVA

However, it is clearly noticed by Figure 10 that the oscillations in frequency of this last case are greater than in the case before, where the generator was generating 3 MVA, because the power that was been generated, before the islanding, is higher in the second case. As the system was operating in steady state the P_m and P_e presented similar values. So, after occur a reduction in the value of P_e in the system, the P_m that is controlled by the speed governor starts to decrease, but since it actuate in a mechanical variable its response time is very slow, allowing a larger oscillation in the frequency of the system.

$$\frac{d^2\delta}{dt^2} = \frac{\omega}{2H} \cdot (P_m - P_e) \tag{3}$$

Before the islanding the generator presented a power angle of 37.2°, and after the islanding happens, this angle dropped to 27.6° as a result of demand reduction, Figure 11. This way, the change in the power angle of the generator machine was then greater, causing the system to take more time to stabilize in a new operation point. As presented by reference [12], an oscillation in the machine's power angle can cause oscillations in the frequency as well as in the voltage, which can even cause voltage fluctuation, voltage sag, and voltage swell, that reflects negatively in the power quality parameters.

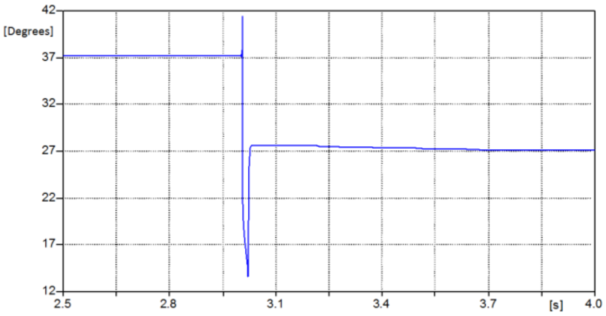


Fig.11. Power angle of case study 6 generating 4MVA

4. Conclusion

After all the case studies were completed we can clearly notice that the relay modelled in the software ATPDraw was very effective in the islanding detection. Other fact that can be emphasised is the detection time, which remained below 6 ms for all the cases, mainly as a result of the speed the values of frequency are refreshed in the relay because they are recalculated after each new iteration in the software.

With this model of islanding detection relay running, to be utilised on ATPDraw, the possible studies to be performed in the platform are further expanded for the reason that in addition to allow the study of a distributed generation system it will be possible to verify the existence of islanding in the system, which will, for example, allow a survivor study for microgrid for an intentional islanding situation because as the ROCOF recognizes that the islanding occurred both the voltage and speed controllers of the generator machine can adapt from a condition they were operating in parallel with the grid to a condition where the generator will feed all the loads connected independently .

Other studies are been carried to validate this relay and analyse possible point of non-detection and false-trip.

For future studies, we pretend to analyse the functionality of this relay with different types of load, since the analysis here presented was done considering only constant impedance loads.

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