RISK OF STABILISATION OF ISLANDING SITUATIONS BY LOCAL REGULATIONS

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ABSTRACT

New local regulations are more and more implemented on decentralized generators connected to distribution networks in Europe. These regulations are for instance :

- *Q = P tan φ : local voltage control through reactive power absorption or injection linearly correlated to the active power produced by the generator.*
- *Q(U) : local voltage control through reactive power absorption or injection correlated to the voltage measured at the connection point of the generator.*
- *P(f) : active power response in case of high or low frequency in order to ensure stability of the power system.*
- *Q(f) : islanding detection through frequency shift method. Reactive power is absorbed or injected in order to move the frequency of an islanded part of the network. Implementation details of frequency shift based islanding detection depend on manufacturers.*

These regulations have each been developed for a given purpose (voltage control, system stability, islanding detection) without coordination with each other.

As a consequence, their combined impact on the power system must be studied, in particular in case of islanding situations in distribution networks.

This paper shows that in islanding situations, these local regulations interact with each other.

In particular, the paper focuses on the P(f) and Q(U) regulations which, operating both simultaneously without delay and with instantaneous frequency and voltage measurements, may even stabilize islands.

When either P(f) or Q(U) act alone, they impact the evolution of parameters of the islanded network. However we have not so far highlighted stabilization of island situations due to one of these regulations acting alone.

We have not highlighted interaction of P(f) and Q = P tan φ that stabilize islands either, nor interaction of P(f) and/or Q(U) with Q(f), as modelled in this paper, that contradict Q(f) action enough to stabilize islands that Q(f) alone would have otherwise destabilized.

The paper concludes that when P(f) and Q(U) are used, their respective actions should be decoupled over time in order to avoid island stabilization on distribution networks.

NOTATIONS

In the following, P and Q are the active and reactive power respectively produced by the decentralized generator, U and φ the voltage amplitude and the phase angle between voltage and current respectively at the connection point of the decentralized generator, f the frequency of the system, P_n = 1MW the nominal power of the decentralized generator considered in the study, ΔP and ΔQ the active, respectively reactive, power supplied by the main network to the feeder before islanding.

INTRODUCTION

Decentralized generators are now more and more required to be capable of providing services to the power system. Indeed, various regulations have been or are being implemented or planned by national and European rules for decentralized generation connected to the distribution systems. In particular (but not exclusively) we have :

- *Q = P tan φ* : local voltage control through reactive power absorption or injection linearly correlated to the active power produced by the generator.
- *Q(U)* : local voltage control through reactive power absorption or injection correlated to the voltage measured at the connection point of the generator.
- *P(f)* : active power response in case of high or low frequency in order to ensure stability of the power system.
- *Q(f)* : islanding detection through frequency shift method. Reactive power is absorbed or injected in order to move the frequency of an islanded nerwork. Implementation details of frequency shift based islanding detection depend on manufacturers.

These regulations have each been developed for a given purpose without coordination with each other. Q = P tan φ and Q(U) are sponsored by DSOs. P(f) is meant for the stability of the whole European power system and required by some TSOs and ENTSOE [1]. Q(f) parameters differ according to manufacturers.

As a consequence, the combined impact of these regulations on the power system needs to be studied, in particular in case of islanding situations on the distribution network where frequency and voltage are not controlled any more by the main power system nor by tap changers at the HV/MV substation, but depend on balances in active and reactive power in the islanded part of the distribution system.

LOCAL REGULATIONS

Q = P tan φ : tan φ is usually chosen as a fixed value (or

to be adapted in Winter and Summer) to improve overall voltage management on feeders. In France, values for tan φ are typically in the [-0,35 ; +0,4] range for medium voltage networks.

Q(U) : the Q(U) regulation may have various forms but the basic idea is to absorb reactive power when voltage is high and to supply reactive power in case of low voltage. In this paper, we will use the following shape for Q(U), with dead-band, as well as parameters of the same order of magnitude as those that may be applied in France in the future :

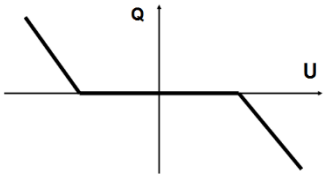

Fig 1 : typical Q(U) regulation curve

P(f) : the P(f) regulation has the following shape :

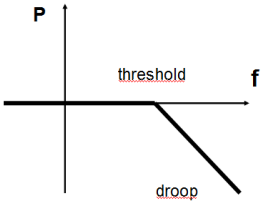

Fig 2 : typical P(f) regulation curve

In its RfG network code, ENTSOE [1] requires the threshold to be in the [50,2 – 50,5 Hz] range, the droop in the [2-12%] range and that P(f) act as fast as technically feasible.

Q(f) : frequency shift may be implemented in various ways. For instance:

A method is the positive feedback frequency shift that aims at amplifying frequency variations through absorption/injection of reactive power. Then, one may wait to reach the generator interface protection limits to disconnect the generator or alternatively implement an embedded intelligence that will link frequency increase/decrease and reactive power absorption/ injection and command disconnection before reaching generator interface protection limits. Such type of positive feedback frequency shift is now standardized in Japan in low voltage [2].

Another way consists of periodic reactive power injection/absorption cycles and observation of the response of the system. When islanded, the islanding protection may measure frequency disturbances, e.g. high df/dt, or voltage phase jumps following current phase jumps, and identify an islanding situation.

Other algorithms may use the link between reactive power absorption/injection and frequency variations.

GRID MODEL USED

A simplified model of a distribution feeder with a load made of 70% static load and 30% asynchronous motor has been used. This model is illustrated on Fig. 3.

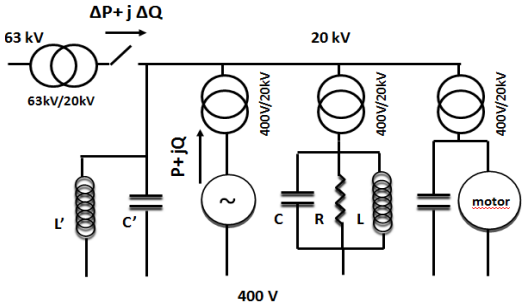

Fig 3 : model used for simulations

It consists of :

- a 1 MW inverter-based generator. $P=P_n=1$ MW. $Q=0$.
- a compensated induction motor that consumes 307 kW and close to 0 kVAr reactive power at nominal conditions. The reduced inertia of the motor is 0,93 MWs/MVA as an average of residential and industrial motors (see [3]).
- a capacitance C' to compensate for the reactive power consumed by 20kV/400V transformers.
- an adjustable inductance L' to create reactive power unbalances.
- a RLC load. In the reference case, this is at nominal frequency 50 Hz, 20 kV voltage on the feeder, R, L and C are adjusted so that the inductive power and the reactive power consumed by the inductance L, respectively produced by the capacitance C, are each 680 kVAr and the active power consumed by the resistance R is 673 kW. So the resonance frequency of the RLC load is 50 Hz and its quality factor about 1.
- if $L' = \infty$, $\Delta P=0$, $\Delta Q=0$.

Simulations are performed on Matlab/SimPowerSystem.

Simulations with this simplified model aim at understanding the general principles of the problem. They cannot reproduce all the real situations and the associated complexity that may be met on the field (like settings of regulation parameters, frequency and voltage measurement methods, interaction of many generators with each others, impact of different load types, ...).

INTERACTION OF P(f) AND Q(U)

In this part, we consider neither Q(f) nor $Q = P \tan \varphi$.

Case of a reactive power unbalance

We consider an example where $\Delta Q = 10\%\ P_n$ (before islanding the feeder consumes $10\%\ P_n$ of reactive power more than it produces) and $\Delta P=0$ (before islanding the feeder is balanced in active power). Islanding occurs at t=0,5 s. Various situations are considered :

Both regulations P(f) and Q(U) are deactivated

When islanded, the system finds a balance at about 53,2 Hz, which is outside of the wide generator interface protection range authorized in France [47,5 - 51 Hz]. So the island will be detected and terminated.

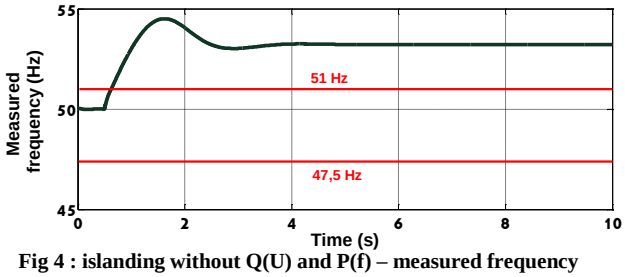

Fig 4 : islanding without Q(U) and P(f) – measured frequency evolution

Both regulations P(f) and Q(U) are activated and act without neither delay nor filtering

P(f) acts without delay, with a threshold of 50,2 Hz and a droop of 12%. Q(U) uses the instantaneous voltage measured at the connection point.

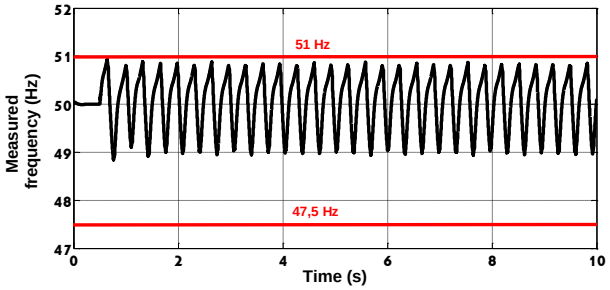

Fig 5 : islanding with Q(U) and P(f) acting without neither delay nor filtering – measured frequency evolution

In that case, measured frequency remains bound within a [48,8 - 50,9 Hz] range included in the generation interface protection range [47,5 - 51 Hz]. Voltage also remains within the [80% - 115%] range of interface protections (see Fig 8). The island is not detected.

To explain this result, we may observe the operation of both regulations P(f) and Q(U) as well as the evolution of voltage and measured frequency. We zoom the observation on a 2 s period.

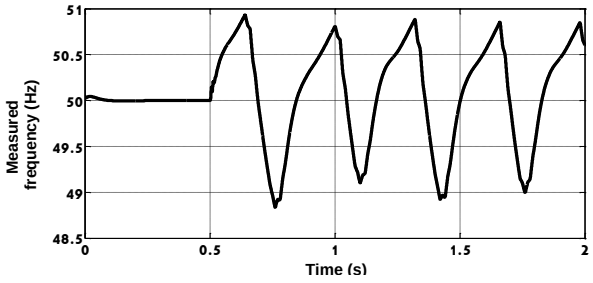

Fig 6 : islanding with Q(U) and P(f) acting without neither delay nor filtering – measured frequency evolution

The measured frequency depends on the parameters of the PLL of the inverter as PLLs require time to measure frequency accurately. So, especially in case of oscillations, the measured frequency differs from the actual frequency on the feeder. The action of *P(f)* induced by the measured frequency is presented in Fig.7 (active power reduction setting) :

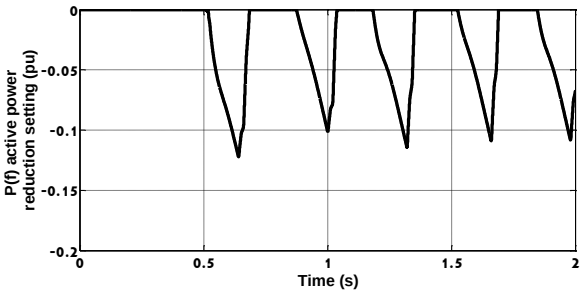

Fig 7 : islanding with Q(U) and P(f) acting without neither delay nor filtering - P(f) action

Variations of P induce the following voltage variations :

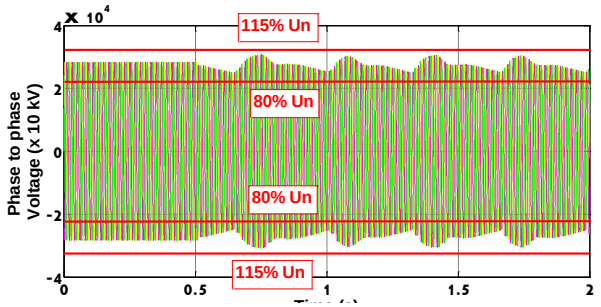

Fig 8 : islanding with Q(U) and P(f) acting without neither delay nor filtering – measured voltage evolution

Voltage variations induce the following Q(U) action (tan φ setting) :

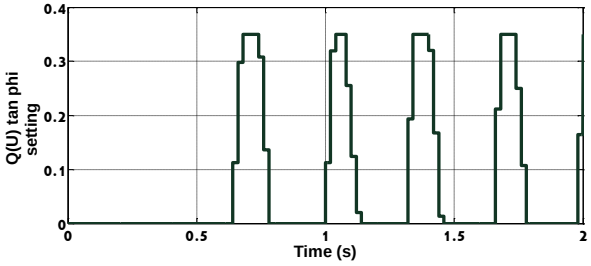

Fig 9 : islanding with Q(U) and P(f) acting without neither delay nor filtering – Q(U) action

The explanation for the behaviour of the system is the following : after islanding, the reactive power unbalance in the system pushes the frequency up above 50 Hz. When the 50,2 Hz threshold is crossed, the P(f) regulation reduces the active power produced by the generator. This reduction in active power available causes a drop in voltage of the islanded feeder. When the low end of the Q(U) dead-band is crossed, the Q(U) regulation commands a reactive power injection. This rapid injection of reactive power forces the frequency down to maintain the reactive power balance in the

system. The decrease in frequency induces an increase in active power produced by the generator through the P(f) regulation and therefore an increase in voltage which will command an end to reactive power injections. And we come back to the beginning of the cycle which starts all over again.

With parameters used for P(f) and Q(U), above $\Delta Q = +10\%\ P_n$ reactive power unbalance, interface protection limits are reached. We tested other parameters. For instance a 2% droop, still with a 50,2 Hz threshold for the P(f) regulation, allows to maintain the system within the [47,5 – 51 Hz] range even with a higher initial reactive power unbalance, up to $\Delta Q = +30\%\ P_n$.

However, if the reactive power unbalance is reversed (this is at nominal conditions the feeder produces more reactive power than it consumes ($\Delta Q < 0$)), after islanding, the frequency initially goes down and we do not witness stabilizing cycles. The reason is that the P(f) regulation considered does not provide for active power increase in case of low frequency, symmetrically to the active power reduction it provides in case of high frequency. Q(U) operates alone and cannot maintain the island. If P(f) provides an active power increase under a certain threshold in case of low frequency, we verified that islands are stable with negative values of ΔQ.

Both regulations P(f) and Q(U) are activated, Q(U) without delay and P(f) with a delay

As shown in Fig.10, P(f) acts with a 2 s delay. After this delay, it is activated taking into account the instantaneous frequency. Q(U) uses the instantaneous voltage measured at the connection point. We obtain the following result for measured frequency :

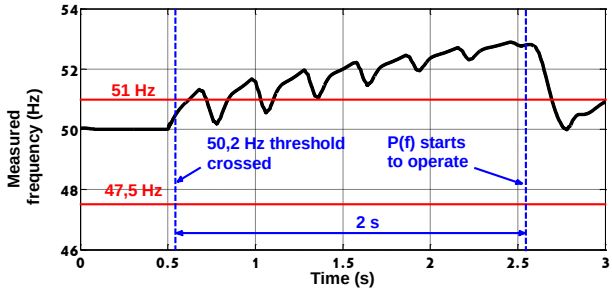

Fig 10 : islanding with Q(U) acting without delay nor filtering and P(f) acting with a 2 s delay – measured frequency evolution

In that case, the delay of P(f) allows to avoid islanding. During the 2s when P(f) does not operate, Q(U) acts alone and is not able to stabilize the island even if, in that case, its action slows the frequency drift.

Both regulations P(f) and Q(U) are activated, Q(U) with a delay and P(f) without delay

P(f) acts without delay. Q(U) uses in that example a 5 s mean average voltage measurement. We obtain the following results :

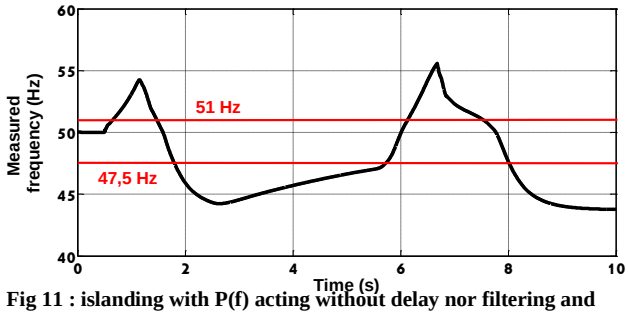

Fig 11 : islanding with P(f) acting without delay nor filtering and Q(U) acting with a 5 s averaging for voltage measurement - measured frequency evolution

We see that using a mean average for voltage measurement allows to differ the action of the Q(U) regulation and in that case allows to detect the island.

Both regulations P(f) and Q(U) are activated, both with delay

P(f) acts with a 2s delay. Q(U) uses a 5 s mean average for voltage measurement. As a result both regulations do not operate during at least the 2 first seconds of the islanding, which allows to detect the island.

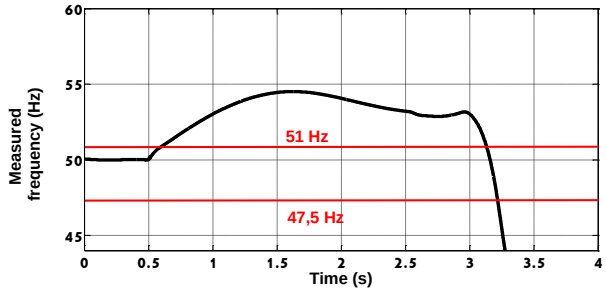

Fig 12 : islanding with P(f) acting with a 2 s delay and Q(U) acting with a 5 s averaging for voltage measurement - measured frequency evolution

Case of an active power unbalance

So far, we have studied reactive power unbalances. In case of active power unbalances (obtained by changing R in the model), if P(f) and Q(U) act both without delay and simultaneously, we also witness stabilization.

For instance, in case of excess of active power generation on the feeder compared to consumption, just after entering islanding voltage will increase, which will induce through Q(U) an absorption of reactive power by the generator. This will in turn induce an increase in frequency which will, through P(f) cause a reduction of active power produced by the generator : in the same way as in the case of a reactive power unbalances, we will initiate a cycle and the island will be stabilized.

However, if initially the feeder consumes more active power than it produces, after entering islanding, voltage will go down, which will induce a generation of reactive power by the generator through Q(U). This injection of reactive power in the system will push frequency lower. If the P(f) regulation does not provide an increase of

active power in case of low frequency, there will be no increase in active power, no increase in voltage, no disappearance of reactive power injection and in the end no stabilization effect of the island. Frequency will keep on decreasing according to the reactive power injected and the island may be detected. Moreover, the use of deadbands in Q=f(U) (see Fig. 1), as it is done in the experimentation on wind farm and PV plants connected to the ERDF network [5], as well as in P(f) (threshold in Fig. 2) tend to reduce the risk of island stabilization.

Case of an active and reactive power unbalance

If P(f) and Q(U) act immediately without delays, with P(f) acting only in case of high frequency, islands which consume less active power and/or more reactive power than they respectively produce may be stabilized.

If P(f) acts both in over- and under frequency, islands with any initial unbalance conditions may be stabilized.

INTERACTION OF P(f) AND Q = P TANΦ

In case the Q(U) is replaced by a Q = P tan φ regulation, we could not, with the model used, identify islanding stabilisation unless in the very particular case where the Q = P tan φ exactly compensate for the reactive power initial unbalance. In that case, the frequency remains at 50 Hz and voltage at 20 kV when islanding occurs.

The reason for this is that a regulation Q = P tan φ does not provide compensation for the variation of voltage.

INTERACTION OF Q(f) WITH P(f) AND Q(U)

As mentioned, various ways are used to implement Q(f).

Methods that use periodic injection/absorption of reactive power do not influence significantly the balance of the system as their effect is nul over time.

So we modelled a positive feedback frequency shift method. We used two methods :

- shift of the phase angle in the PLL of the inverter with a rotation by an angle θ_{SFS} defined according to the formulas (3) and (4) in [4] : $\theta_{SFS} = \pi/2\ [cf_o + k_{SFS}(f-f_o)]$. cf_o and k_{SFS} are constants. f_o = 50 Hz.
- add to the reactive power setpoint given by the Q(U) regulation an additional term $\Delta Q = K(f- f_o)$, similarly to the method presented in [2].

Various k_{SFS} and K values have been tried, each able to destabilize the system in the absence of P(f) and Q(U).

In the examples taken, we identified interactions between P(f), Q(U) and Q(f). However we did not meet situations where the effect of the frequency shift Q(f) was annihilated by P(f) and/or Q(U) and where islands which Q(f) alone would have destabilised were stabilised. This point may require further study.

CONCLUSION

This paper showed that P(f) and Q(U) regulations, used simultaneously and without delay neither in the frequency and voltage measurements nor in the action of both regulations, may stabilize islands.

When delays are applied in either P(f) or Q(U) regulations, or in both, the larger the delay, the more the stabilisation effect vanishes.

This effect is similar to the combined stabilisation effect for the power system of primary frequency and voltage regulations implemented on large generators connected to the transmission system.

Hence, this potential interaction should be kept in mind when deciding the parameters of both P(f) and Q(U).

To avoid islanding or at least reduce the risk of islanding, it should be verified in real networks that such a stabilizing effect will not occur. A way to avoid the stabilisation of islands is to decouple the action of Q(U) and P(f) regulations by delaying them over time.

This decoupling may for instance be provided by averaging or filtering the voltage measurement used for Q(U) (which is the usual way to measure voltage) or by delaying the action of P(f), or both.

In case Q(U) voltage measurement is averaged or filtered, it must be checked that Q(U) does not interfere with voltage regulation at the tap changers of the feeder. For instance, if Q(U) is chosen to act faster than tap changers, there will be an upper limit on the voltage averaging or filtering delay not to be exceeded.

Another way currently investigated and used on ERDF network to avoid the stabilisation effect of P(f) and Q(U) is to replace P(f) in each generator by a "fleet" effect obtained by staged disconnections and reconnections of generators at various frequencies (e.g. 50,2 Hz, 50,4 Hz, 50,5 Hz, 50,6 Hz, …). This method must be compatible with power system stability requirements.

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