Intentional Islanding for reliability improvement in distribution networks with high DG penetration

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***Abstract*-- In this paper, a new operational strategy regarding islanding operation is presented exploiting Distributed Generation for islanding purposes. The presence of DG may be used to enhance reliability to final consumers by providing an alternative power source when there is an interruption in the upstream network. The feasibility of this type of operation in distribution networks is analyzed in a case study by analyzing the behavior of different generating units and protection settings.**

***Index Terms*--Dynamic behavior, distributed generation, islanding operation, power system protection, power system relays**

I. Introduction

The increased penetration of Distributed Generation (DG) in distribution networks brings out the possibility to adopt new operational strategies that may contribute to improve system reliability. One of these new operational strategies regards allowing islanding operation by exploiting DG units when failures in the upstream network occur. In this context, islanding takes place when part of the system becomes electrically isolated from the interconnected power system.

Islanding operation demands additional technical requirements like a large increase in protection complexity and specific frequency and voltage regulation capabilities from DG units. Regarding protections, one must not neglect that protections are set on a radial network basis.

While voltage regulation capability is somewhat more frequent in DG units, frequency regulation is not that usual. Nevertheless, for one to admit the possibility of islanding operation, frequency regulation is necessary, even if installed only in some facilities.

It is important to stress that the common operation mode of the existing distribution networks is still to avoid islanding in all situations, especially whenever an unexpected disturbance occurs in the system.

While it is difficult for distributed generation to survive an unplanned island, for example caused by a fault, current technologies allow network operators to use distributed generation in a planned islanding in order to avoid loss of load for predictable situations such as maintenance or repairs in the upstream grids.

In this paper one discusses the feasibility of adopting islanding operation in distribution networks with DG by studying the behavior of different types of generating units and the additional requirements, in terms of protections, that are needed for this purpose.

II. System Modeling

i. Network

A 60 kV Distribution network with large penetration of distributed generation, including hydro, wind and diesel based, located in the north of Portugal, was chosen for the study [1]. The simulations were made using the EUROSTAG commercial transient simulation program.

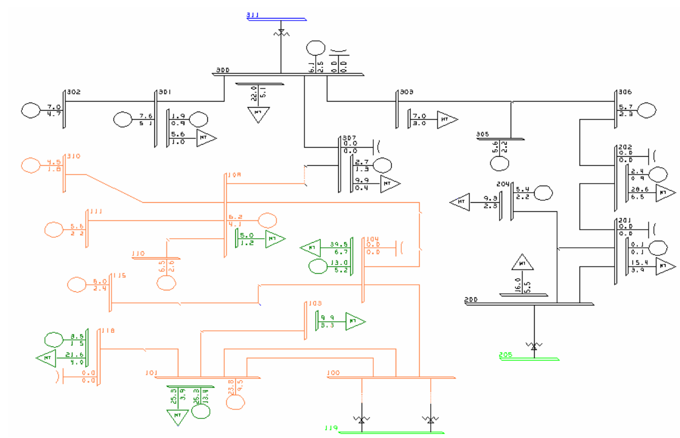

Fig. 1 – Studied 60 kV Distribution Network

The part of the network to be isolated has 76.18 MVA of installed hydro capacity, 66.1 MVA in wind based generation and 5.8 MVA in thermal units. During off peak hours, the network consumption is about 102 MVA and in valley hours 47.1 MVA. Evaluating these figures one can assume that the isolated network is self-sufficient concerning load supply. The large dependence on hydro production leads, however, to a significant variation between dry and wet scenarios, leading to dissimilarity in the interconnection power flow. The study was therefore mainly divided between winter and summer scenarios. Beyond seasonal classifications, studies were also divided according to protection devices settings. In Portugal, distributed generation usually has interconnection protections set for instantaneous tripping, a situation that offers a significant limitation to islanding operation. Thus, for each seasonal scenario, simulations were made considering the existing instantaneous tripping and another sub-scenario where protection settings were relaxed, either in terms of time or pickup values.

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- Winter Scenarios

Winter scenarios were divided between dry and wet, assuming hydro production of 95% and 30% of its rated active power respectively. In wet scenarios, the hydro production has enough capability, together with thermal and wind sources, to fulfill the local load demand, as long as enough regulation capability is available. Each of these scenarios was then further subdivided considering wind power production, being considered that in winter wind power would assume either 20% or 60% of its nominal value.

- Summer Scenarios

Summer scenarios were divided between dry and wet periods, assuming hydro production to be 10% or 20% of its rated active power respectively. In both scenarios, the very low hydro production together with the fact that most of the frequency regulation is performed by these units greatly reduces the success of islanding. Two wind generation scenarios, corresponding to 10% or 30% of rated output power, were defined. Nevertheless, load disconnection is mandatory when islanding occurs due to the lack of frequency regulation.

It was assumed that all synchronous machines have voltage regulation capability while only some of them are able to provide the frequency regulation support. Four hydro and one thermal unit were equipped with speed governors, granting frequency regulation capability inside the island. In addition to synchronous groups, variable speed synchronous generator wind turbines also provided voltage regulation.

One of the reasons why this network was an interesting case study is that, in addition to having a large penetration of distributed generation, it had significant size and detailed information about consumption, production and protection devices was available.

The part of the network that was considered as isolated from the rest of the system is highlighted in a lighter color in figure 1. This study investigated more than 15 different base scenarios, considering peak and valley hours in terms of consumption. In each one of them different hydrological regimes were also considered as well as different settings for network and interconnection protections (instantaneous or not). This led to a more than one hundred studies.

ii. Network components

In order to proceed with an accurate study in terms of dynamic behavior, all generation units were represented by their dynamic models.

Recent wind energy converters, have a dynamic behavior that is very different from induction-generator based machines. For this study both wind power technologies were considered as there was information about the type of machine each DG facility had installed.

- Asynchronous Generator wind turbines

The asynchronous wind turbines were modeled using a conventional third order approximation, neglecting the fast rotor transients [2].

All the asynchronous machines have group transformers and capacitor banks to fulfill its reactive power needs and to provide the mandatory power factor.

- Variable Speed Synchronous Generator wind turbines

Variable-speed wind generators were also included in this study, with a model described in [3] that, despite being simple, reflects what we believe to be its behavior. Electronic interfaces are in fact capable of filtering the mechanical behavior of the turbine to the network and are commonly used by some major turbine manufacturers. Functionally, these generators are modeled as a controllable active and reactive power source, using a first-order model representing a spinning mass connected to a voltage-source converter that presents controllable electrical torque.

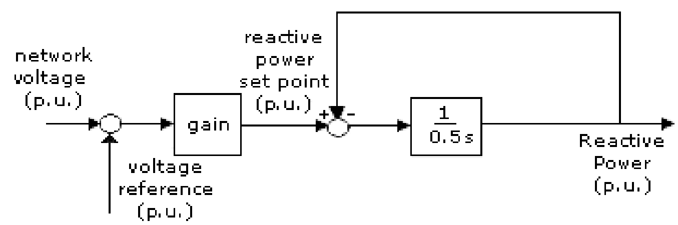

Fig. 3 – Active Power Loop

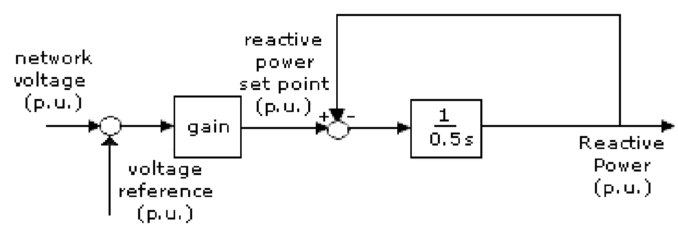

Fig. 4 – Reactive Power Loop

The two former figures represent the referred active and reactive power loops adopted in this representation. Such modeling was transposed to the EUTOSTAG environment using the macroblock® functions and working independently. The reactive power loop is sensitive to network voltage, whereas the amount of active power injected is only dependent on wind speed. A current-measuring block will control the maximum reactive power to be injected in order not to surpass rated apparent power.

Group transformers are included in all machines with the reference voltage chosen to provide voltage levels around 1 p.u.

- Synchronous Generators

Synchronous generators are modeled using a fourth-order model, according to Park's classical theory, in which the rotor is represented solely by the exciter winding in the direct axis and no winding along the quadrature axis.

Voltage regulators were included and modeled with an IEEE type 1 model and speed regulators according to [3].

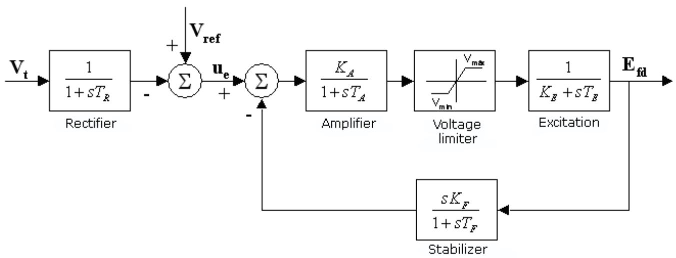

Fig. 5 – Voltage Regulator

The chosen parameters were based on simulation experience and reference literature.

As far as frequency regulation is concerned, a PI control was used as described in figure 6. Both integral and proportional gains assumed different values considering the type of DG units, as well as the type of turbine, which can be classical thermal or hydro [4].

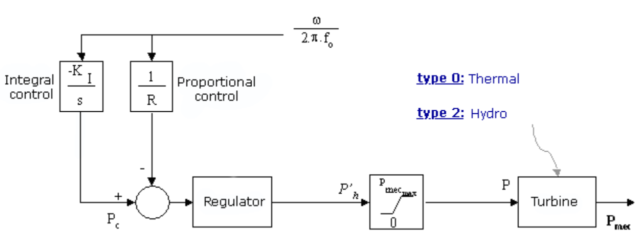

Fig. 6 – Frequency Regulator

The presence of an integral loop aims at eliminating steady state error in frequency. As islanding is in fact a temporary situation, synchronization with interconnected network requires that frequency assumes the same value. The values assumed by the different parameters considered the type and characteristics of machines as a result of the significant difference between hydro and thermal units behavior. Hydro turbines have the water starting time phenomena that implies a slower response to frequency network variations.

- Network and DG units protection devices

Since islanding operation is not a common practice, existing relaying adequacy must be evaluated.

Network and interconnection protection devices were modeled and their settings determined according to Distribution System Operator (DSO) information.

The DG interconnection unit protection devices are the following:

- Max. frequency relay
- Min. frequency relay
- Max. voltage relay
- Min. voltage relay
- Max. zero sequence voltage relay

These protections had been initially set for instantaneous tripping. In order to allow successful islanding, different scenarios were considered in which these settings were changed [5].

Network protection concerned typical line and transformer devices, capacitor banks tap changing protection and frequency load shedding relays in every MV panel. The corresponding parameters were provided by the DSO.

Two distinct sets for protection devices were subsequently established: one for normal operation mode with instantaneous tripping and another for islanding operation mode.

III. Intentional Islanding Procedure

In order to obtain a well succeed intentional islanding a set of simple procedures must be defined before. Mainly this consists in reducing the power flow in the line to be opened before separating the distribution grid from the upstream network. This reduction must be performed by disconnecting some load inside the island to be formed and or increase local generation if possible. Such a reduction in power flow is desired to avoid protection tripping that may take place in the island following the isolation. However, to increase the success of this action a relaxation in the protection settings should be envisaged, by addressing namely interconnection relays and load shedding relays.

After forming the islanded network, any loads or generation that were disconnected to reduce interconnect flow prior to isolation are considered for reconnection if enough generation availability occurs. When the maintenance or repairing action that motivated islanding is completed, both networks can be reconnected through the appropriate synchronism check relay.

IV. Simulation and Results

Dynamic simulation results are presented next to illustrate the feasibility of the islanding operation procedure studied. This study included a dynamic behavior analysis of the isolated network for a longer period in time, compared to typical dynamic studies, because of the need to evaluate if, besides being capable to survive to the islanding, this network had the capability to satisfy consumption with proper quality of service.

As described in section III, the islanding takes place for an almost generation / consumption balanced island, leading to the co-existence of two separate systems with different frequencies. This procedure fulfills the prior objective to improve quality of service to the customers, allowing repair or maintenance actions to take place in the upstream networks without major loss of load. Each situation must be properly studied and a complete set of representative scenarios defined in order to determine the extent to which planned islanding may be possible and useful.

The power flow analysis of the opening point has major importance in this procedure. Even with protection settings relaxed, the reduction of power flow in the circuit breaker is in all cases important. The tests that were made clearly revealed that, only in winter when hydro production reaches its highest level, all the island load is able to be served during isolation. Load disconnection prior to separation is necessary in all other cases. A precedence load disconnection criteria was therefore developed following operator instructions and regional weights. On the other hand, in some winter scenarios, where production levels are very high, isolation can require generation disconnection.

The scenario chosen for presentation in this paper is an off-peak dry winter one, with wind power at 50% of its nominal capacity.

The following figures show the time evolution of system frequency, voltage in two buses and injected power in two DG units with and without frequency regulation.

The simulation shows the moments before separation, where networks are still interconnected, and the behavior of the separated network when changing generation and load. Isolation time is set to 1000 s.

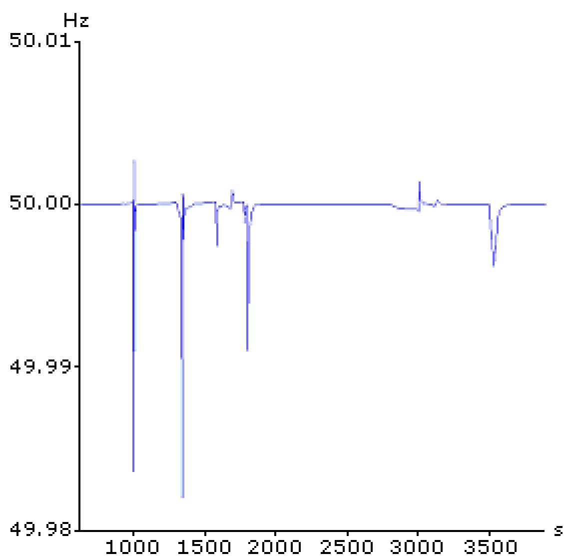

Fig.7 – System Frequency

Figure 7 shows that frequency deviations reach a minimum of 49,983 Hz (during load reconnection), which is within an acceptable range for isolated networks. The system was able to sustain reconnection of all the initial load in four distinct time steps without tripping of machines or load shedding relay operation.

In terms of voltage, as shown in figure 8 for two significant MV load buses, after initial rise of overall network voltage at the time of isolation owing to net reactive power export immediately before disconnection, the final value is overall very close to initial values. This behavior is representative and can be extended to the rest of the network.

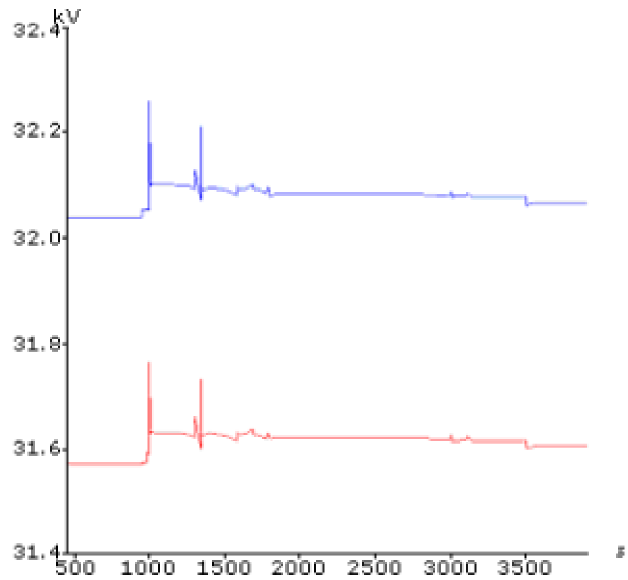

Fig.8. Voltage at 30kV buses

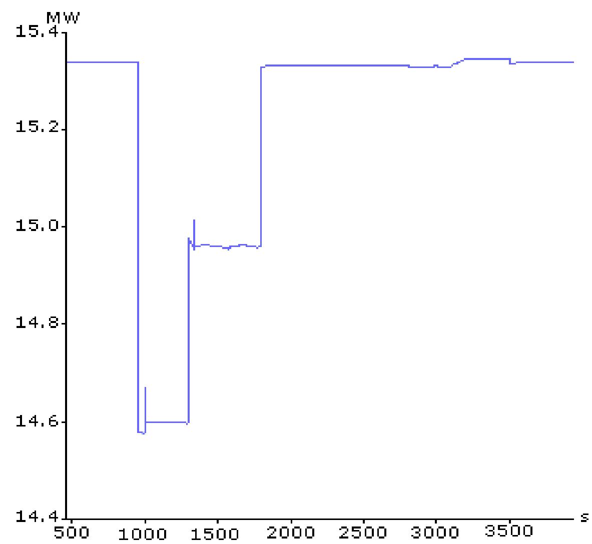

Fig.9. – Load at 30 kV bus

This scenario was balanced in terms of production/consumption in the network to become islanded. The load was nevertheless reduced before islanding because protection devices were left with existing instantaneous settings. This measure intended to study a pessimist scenario as any deeper variation in frequency or voltage would trip out generation. In figure 9 it is clear that all the load is reconnected, this process being divided in two major steps to ensure that frequency deviation was not too extensive. The final two changes (3000 and 3500 s) in load correspond to normal consumption increase, characterized by a smoother load variation.

Fig.10 – Mechanical Torque in DG hydro unit

One of the difficulties in islanding operation is the need to regulate frequency using distributed generation. Not all the units are provided with this feature and, when available, there must be enough reserve to respond to network needs. In this particular case, one of the major concerns was the slower response that hydro groups have due to water starting time phenomena, as one can see in figure 10.

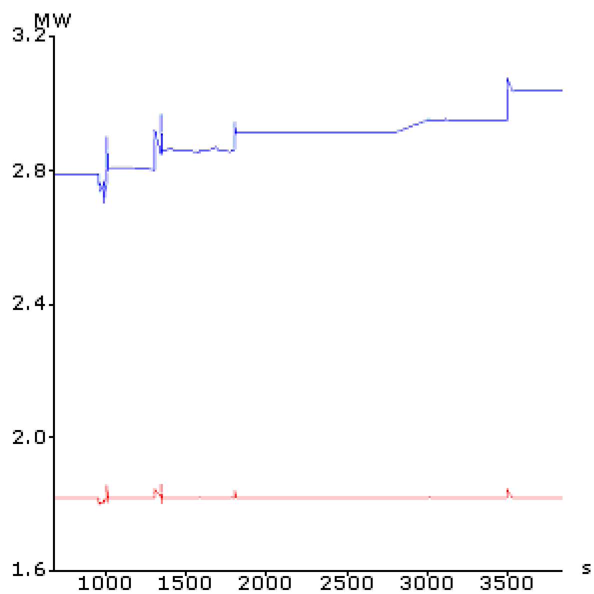

Fig.11– Injected Power by two Synchronous Machines, one with and one without speed regulation

As referred previously, speed regulation is vital to the success of the island. Figure 11 illustrates the action of the frequency regulator, showing time evolution of electrical power in two representative DG units, one with and one without regulation. The top curve represents one of the hydro units responding to frequency changes in the network and the bottom another hydro machine with no speed governor. As load is being reconnected, the machines that provide frequency regulation increase their electrical power to maintain system frequency. The presence of an integral frequency control loop is important to keep frequency at 50 Hz. The increase verified in the generated power shows that the machine is responding to the load increase after isolation.

V. CONCLUSIONS

All the studies indicate that as long as there is enough generation in the part of the network to be isolated, regulation capability in major groups, and a proper reduction of power flow in the opening point, intentional islanding is possible. An operating plan must therefore be defined and the isolation points clearly identified in order to attain the desired reliability improvement.

For the future, the installation of new DG units should include, as a condition or incentive to licensing, an advanced communication system that allow receiving set points in a form of signals. This would enable the network operator or any other form of centralized dispatch to control DG units. Another future demand to DG units, over a certain power, should be the existence of frequency and voltage regulation available to provide active and reactive flexibility, according to network conditions. Both these capabilities would be paid as an ancillary service to compensate the power unable to be delivered to the network by the DG unit, owing to regulation or reserve commitments.

A crucial issue for the success of islanding operation is related with the need to introduce some relaxation on the protection settings of the protection devices installed in the distribution grid. Moreover, at the point of the tie, the breakers need to be closed via synchroscope and check synchronizing relay.

This paper intends to highlight the feasibility of using DG units to provide a new kind of ancillary service that includes voltage and frequency regulation that allow islanding operation, having in mind the improvement of the network reliability.

VI. REFERENCES

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