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EXECUTIVE SUMMARY OF THE THESIS

An analysis of technical aspects related to intentional islanded operation by gensets of MV/LV networks with distributed generation

TESI MAGISTRALE IN ELECTRICAL ENGINEERING – INGEGNERIA ELETTRICA

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1. Introduction

The incidence of faults, the willingness to improve the system security and reliability of the distributed network, as well as the economical drawback related to the fees [1] for the lack of service to end users brought considerable challenges to electricity supply industry, creating further constraints for Distribution System Operators (DSO).

In this scenario, several measures have been taken to overcome these challenges or at least mitigate their effects; islanding a portion of distribution networks after a fault is now considered by DSOs as a way to improve the continuity of power supply. The intentional island is energized by means of GenSets (GS) that work as main power supplies for a portion of the distribution grid.

In the project, the operation of diesel engine-driven synchronous GS is studied. In the first section, the development of the modelling framework for such gensets to operate has been studied; a proper modelling of speed and voltage regulators has been performed.

In the second section to examine the suitability of a GS for islanded operations, numerical simulations have been performed in two scenarios:

- in a Passive Network (PN) employing just a single GS as power supply of the grid;
- in an Active Network (AN) where Distributed Energy Resources (DER) are reconnected to the intentional island and both generators feed the system.

For both scenarios, numerical simulations have been conducted through DigSilent PowerFactory software.

In the result section, the aim of the project is to provide a set of technical regulations to the usage of GS, highlighting the statical and dynamical limits of the proposed solution.

2. Modeling of the islanded system

The GS is the main element to model in PowerFactory software. To properly model the GS, the capability curve of the alternator, the mechanical parameters, as well as the speed governor and voltage excitation system must be considered.

Starting from the electrical and mechanical parameters of the machine (Table 2.1), the software creates the model, as well as the capability curve of the GS.

Parameters	**Implemented values**
Nominal Complex Power [kVA]	400
Nominal Voltage [V]	400
Frequency [Hz]	50
Power Factor	0,8
Poles	4
Direct axis synchronous reactance Xd [%]	330
Quadrature axis synchronous reactance Xq [%]	175
Direct axis transient reactance X'd [%]	29,5
Direct axis sub-transient reactance X''d [%]	13,2
Quadrature axis sub-transient reactance X''q [%]	15,6
Negative sequence reactance X2 [%]	14,4
Zero sequence reactance X0 [%]	3,3
Open circuit time constant (T'do) [s]	1,6
Transient time constant (T'd) [s]	0,145
Sub-transient time constant (T''d) [s]	0,014
Armature time constant (Ta) [s]	0,018
Moment of Inertia (J) [kgm^2]	4,8

Table 2.1: Electrical and mechanical GS parameters

The rating of the GS (An = 400 kVA) is selected because represents a good trade-off between the ease of transport and adequate power to counterfeed an MV feeder.

The speed governor considered is DEGOV1 (Figure 2.1): it can work in isochronous condition or in droop condition. The preferred condition is the isochronous one because the GS is the only rotating generator that supply the system, and the frequency remains always at the nominal value (50 Hz). The main block is the actuator: it provides as an output the required torque to compensate the input frequency error between the reference and actual frequency value.

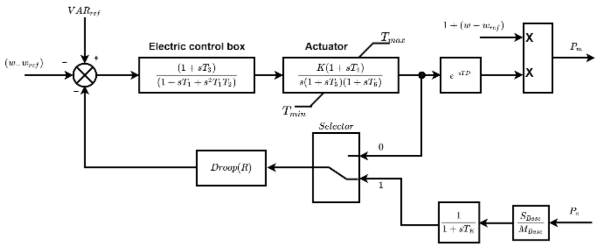

Figure 2.1: DEGOV1 block scheme

The voltage excitation system is EXST2A (Figure 2.2): this regulator can provide a voltage drop if required. As for the previous regulator, the drop condition is set to zero (null droop). For EXST2A, the main component is represented by EFDmax: it is the maximum voltage that the excitation can reach.

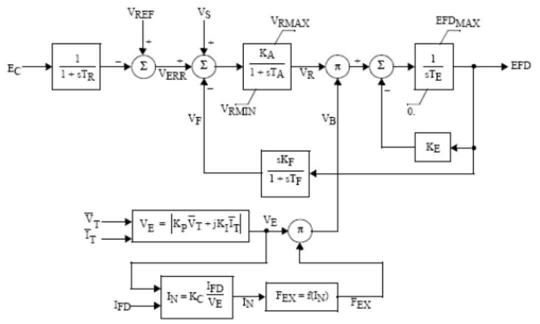

Figure 2.2: EXST2A block scheme

The implemented parameters for both regulators are described in [1] [2].

Passive network study case

In this section, the simulated case study follows the operational practices of the DSOs and consist in a GS connected to the LV busbars of a secondary substation; the GS is used to power a MV feeder after several time after the occurrence of a fault. This grid is called Passive Network (PN).

Then, numerical simulations have been conducted to deeply study the dynamic stability of the islanded system; different parameters (lines, loads, and motors) are changed to analyse the system in different configurations [3].

Active network study case

In this section, following CEI 0-21 [4], after the formation of the island system using a GS, the Distributed Generation (DG) is allowed to automatically reconnect to the network, if these conditions are verified:

- the voltage remains inside 90 ÷ 110% Vn;
- the frequency remains stable in an adjustable range around the nominal value (default 50 ± 0.1 Hz) for a selectable time in the range 0 ÷ 900 s (default value 300 s);
- the power delivery varies gradually with a take-off ramp.

The take-off ramp should not exceed the maximum positive gradient of 20% per minute of the maximum power provided by the DG itself (200 kW in the thesis). The DG unit is modelled as a static generator, current-controlled in direct and in quadrature reference axis currents [5].

If the reconnection process does not cause instability issues, the benefits of the Q(V) and P(f) control laws are evaluated. The aim of the numerical simulations conducted on the AN is to trigger:

- the voltage upper or lower threshold (V1s, V1i) of the Q(V) regulation;
- the frequency threshold (50,2 Hz) of the P(f) regulation.

The implemented control laws have the common characteristic of adapting the active or reactive power supply of the DG unit according to the grid parameters (frequency and voltage).

In particular, the implemented regulations are:

1. Q(V): reactive power regulation for over/under voltage events;

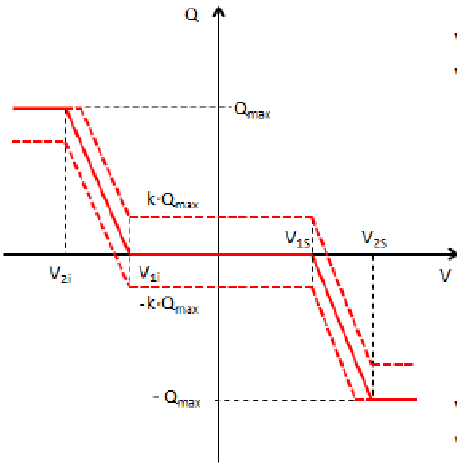

Figure 2.3: Characteristic curve Q(V)

2. P(f): active power regulation for over frequency events.

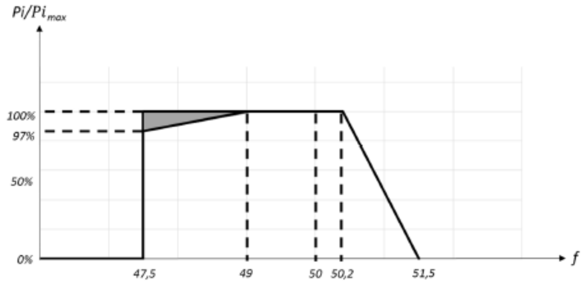

Figure 2.4: Characteristic curve P(f)

In the next table, the activation thresholds are reported for both regulations (Table 2.2).

<table>
<tr><th colspan="2">Q(V) regulation</th><th>V2i</th><th>V1i</th><th>V1s</th><th>V2s</th></tr>
<tr><td colspan="2">[p.u.]</td><td>0,90</td><td>0,95</td><td>1,05</td><td>1,10</td></tr>
<tr><th>P(f) regulation</th><th colspan="2">Frequency threshold</th><th colspan="3">Maximum frequency value</th></tr>
<tr><td>[Hz]</td><td colspan="2">50,2</td><td colspan="3">51,5</td></tr>
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Table 2.2: Q(V) implemented parameters

3. Numerical simulations

Passive network study case

Dynamic stability limits are reached when the operating point of GS is in the under-excited region of the capability curve and the load angle reaches values equals or higher than 60° ÷ 70°.

For each load condition, the length, and the size of the MV line are varied to identify the dynamic limits of the island.

In addition, different load conditions are evaluated:

- no-load condition (P=0 MW);
- partial load condition (P=60%Pmax= 0,192 MW);
- full load condition (P= 90% ÷100%Pmax).

Where:

$$P_{max} = 0{,}8A_n = 0{,}32\ MW$$

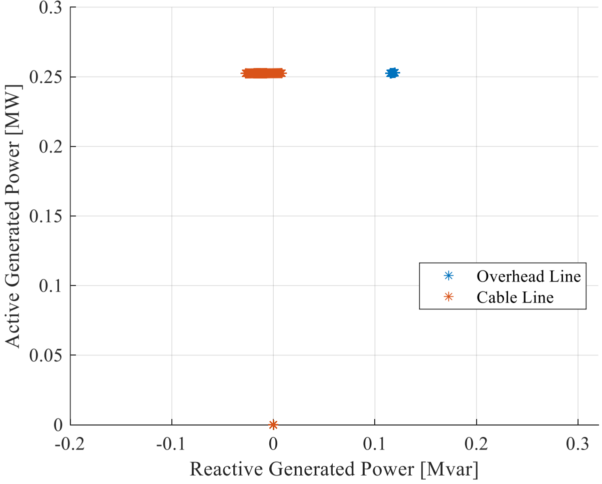

Figure 3.1: Capability curve comparison

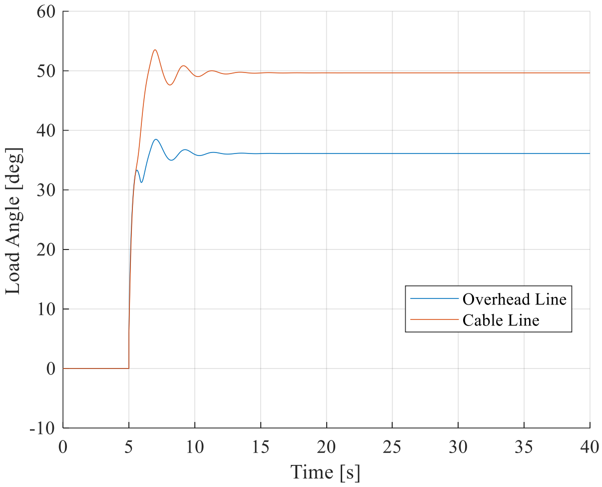

Figure 3.2: Load angle comparison

At 5 seconds, the GS is connected to the grid, and depending on the considered MV line, the operating point moves inside the capability curve. Cable lines have a transversal susceptibility twenty times higher than overhead lines. This means that a system equipped with MV cable lines is more subject to stability issues: the operating point moves towards the under-excited region (Figure 3.1) and the load angle increases (Figure 3.2), reaching dangerous values.

Furthermore, another study case has been performed on the PN. The stability of the island has been checked when a LV three-phase Asynchronous Motor (AM) is connected to the system (Table 3.1). This study case aims to verify if the direct start-up of an AM to the islanded system can cause instability issues.

	AM1 **Single Cage**	**AM2** **Double Cage**
Nominal Complex Power [kVA]	132	132
Nominal Voltage [kV]	400	400
Rated Current [A]	224	220
Frequency [Hz]	50	50
Power Factor cos(ϕ)	0,89	0,84
Poles	2	4
Rated Speed [RMS]	2980	1495
Rated Torque [Nm]	423	410
Starting Torque [p.u.]	2,15	2,9
Stalling Torque [p.u.]	3,1	3,1
Moment of Inertia [kgm^2]	1,96	1,96
Efficiency η [%]	95,6	97,5

Table 3.1: Parameters of AM1 & AM2

Of the presented AM;, single and double cage configurations are analyzed.

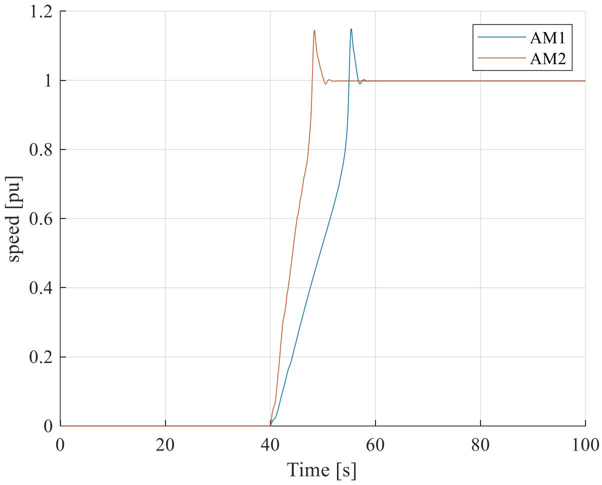

Figure 3.3: AM speed profile

Numerical simulations for the AM study case have been conducted as it follows: the grid is de-energized, and, at 40 seconds the GS unit is connected, and the starting of the AM occurs. The motor at the beginning has null speed (Figure 3.3). The double cage configuration (orange curve) reaches the nominal speed (except for a small slip contribution) 5 ÷ 10 s before the single cage configuration (blue curve). Also, over-speed transient is slightly lower for the double cage.

In addition, the over-current transient has been analyzed (Figure 3.4).

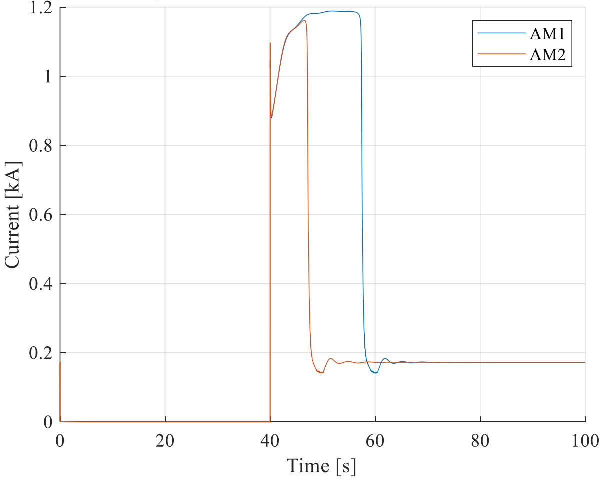

Figure 3.4: AM current profile

The reason for the difference in current profiles is related to the different cage configuration: with double cage configuration, the starting torque is higher, and the starting current is reduced both in time and amplitude.

Active network study case

In the AN configuration, numerical simulations are conducted to identify in which conditions the reconnection process of DG units to the islanded system is possible (maintain the system stable), and, once the reconnection occurs, if the introduction of local regulations could improve some grid parameters. The speed governor of the GS is equipped with a droop different from zero (equals to 4%) to activate the P(f) control law.

When the voltage and frequency of the system are inside the limits imposed by the CEI 0-21, the automatic reconnection the DG occurs. In the study case presented, the reconnection process starts at 100 s, according to the reconnection ramp with a slope equals to 20% of the maximum power of the DG unit per minute (Figure 3.5). Both Q(V) and P(f) control laws are equipped inside the DG unit.

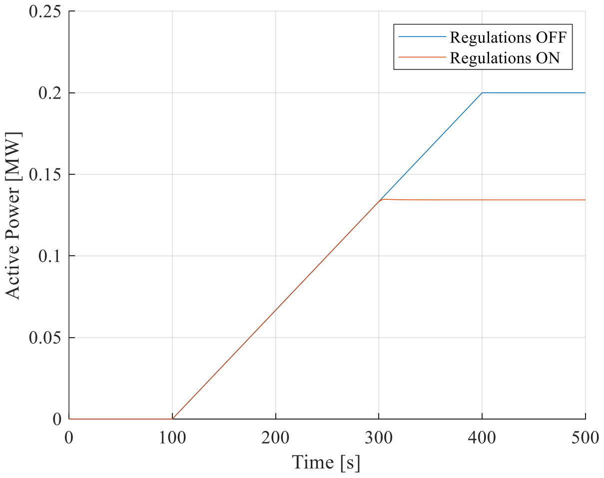

Figure 3.5: Active power exchanged by the DG unit

An increase of active power provided by the DG unit increases the voltage at the connection point: the power flux is inverted. The increase of voltage at that bus is observed in Figure 3.6. Whenever the voltage threshold is reached (1,05 p.u.), and the lock-in value of active power (20%Pmax) overcome, the reactive power is regulated in accordance with Figure 2.3. In this case, the voltage exceeds V1s and so the reactive power is negative, absorbed by the DG unit. In Figure 3.6 and Figure 3.7, the benefit for the islanded system of the Q(V) regulation is shown: if a reactive contribution is exchanged by the DG unit (orange curve), the voltage at the DG bus is reduced compared to the case in which the regulations are off (blue curve).

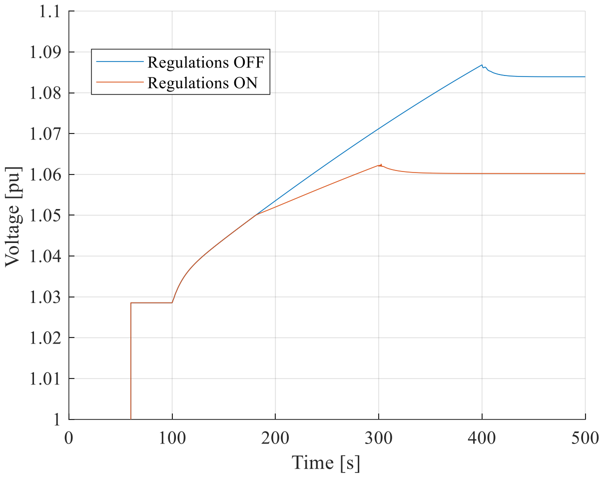

Figure 3.6: Voltage profile at the DG unit bus

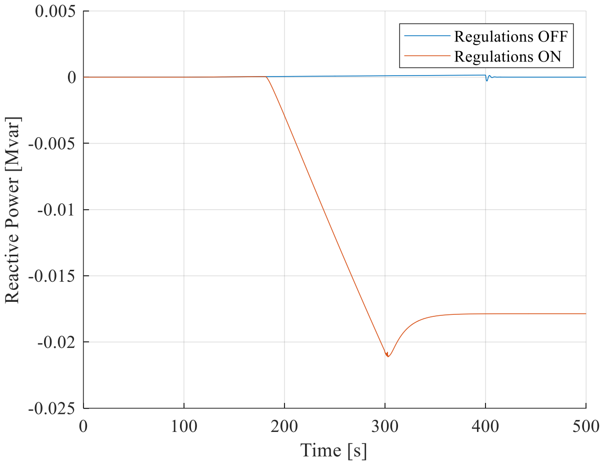

Figure 3.7: Reactive power exchanged by the DG unit

Another benefit for the stability of the islanded grid is provided by the P(f) regulation. In Figure 3.8, the frequency of the system increases because a portion of the active power required by the MV load is provided by the DG unit; from the GS point of view, this means a reduction of the load, resulting in a frequency increase. If the P(f) regulation is off, the GS senses a reduction in the resistive torque, the frequency increases, and frequency protections of the alternator may trip. With the P(f) regulation activated, the frequency is stopped at the frequency activation threshold (50,2 Hz), blocking the reconnection ramp of the DG unit to a specific value (orange curve in Figure 3.5).

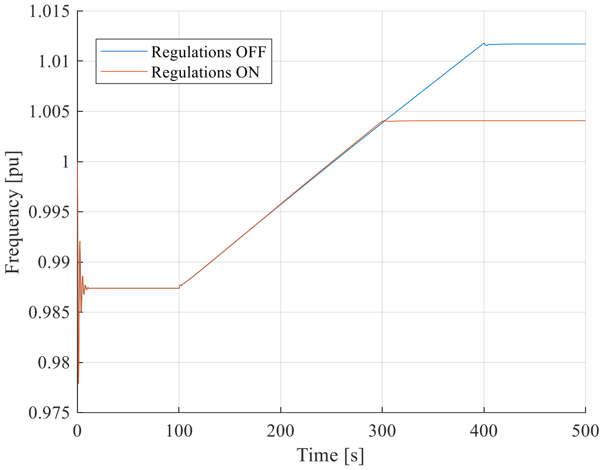

Figure 3.8: Frequency profile at the DG unit bus

Thus, the two regulations provide significant benefits to the islanded system.

In addition, the reconnection limits of DG units have been tested with an additional numerical simulation in which the power produced by the GS (0,10 MW) is lower than the power produced by the DG unit (0,2 MW).

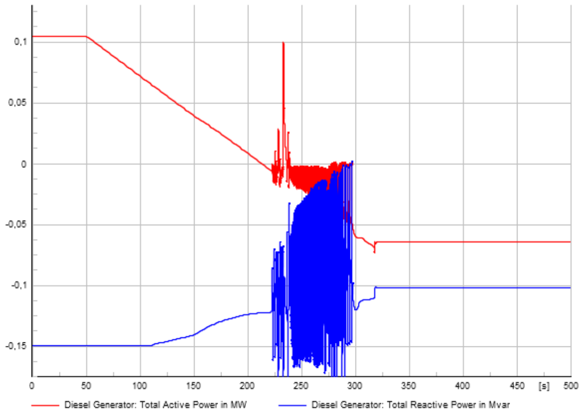

Figure 3.9: Active and reactive power in the motorization process

As Figure 3.9 shows, the stability of the island is compromised due to the transient condition when the GS active power reaches zero. In that instant, the remaining power provided by the DG unit is absorbed by the GS that starts to work as a motor; the frequency is no more controlled by DEGOV1 (turned off when GS active power zeroed) and the behavior of active and reactive power makes the protections trip.

4. Results and Conclusions

The study suggests that the GS counterfeeding process is practically feasible in islanded portions of the grid.

Regarding the PN study case:

- under any load conditions, overhead line-systems (0÷15 km) can be energized by GS, without stability issues for the island. The environments in which most of the lines are overhead ones are rural or mountain areas. In these environments the resolution of the faults may require days; thus, GS counterfeeding process reduces the period of outages, providing a benefit for final users;
- cable line-systems presents stability issues when the length or the size of the line increases upon a certain level (i.e., 9,5 km for full load condition of a 25mm^2 section). This threshold depends on the size of the GS, the length of the cable and on the required power of the load (Table 4.1). Thus, in urban environments, the GS counterfeeding method should be carefully evaluated.

Stability limits-cable line [km]		
Loads	**dynamic**	**static**
85%Pmax	9,5 km	13 km
90% Pmax	9,5 km	12,5 km
94% Pmax	1,5 km	8,5 km
97%Pmax	1 km	5,5 km
Pmax	1 km	2 km

Table 4.1: Stability limits cable lines

Regarding the AN study case:

- all the reconnection processes follow the ramp profile described in the standards;
- the regulation of reactive power Q(V) in case of over/under-voltage events provides a benefit for the islanded system, moving the voltage closer to the nominal value;
- the regulation of active power P(f) in case of over-frequency events provides a benefit for the islanded system; the frequency cannot exceed the activation threshold (50,2 Hz) otherwise the active

power provided by the DG becomes constant.

In conclusion, when reconnected, the regulations Q(V) and P(f) of the DG provide some benefits to the system, helping to maintain voltage and frequency inside the operating limits; however, the reconnection process may create instability to the system. The active power injected inside the system by the DG units should not exceed the effective power produced by the GS. Otherwise, the remaining active power contribution flows inside the GS, inverting the power flux. As seen in Figure 3.9, the if the GS starts working as a motor, it creates high transient behaviours and protections trip immediately.

References

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