DYNAMIC BEHAVIOUR OF DISPERSED GENERATION ON THE PUBLIC MV NETWORK

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INTRODUCTION

The last decade has seen a mushrooming of dispersed generating units connected to the distribution network. This evolution can be explained by changes in the institutional context and by a number of favourable economic factors (advances in generation technology, gas prices, standardisation of generating sets, …).

The MV-distribution networks were designed to operate with energy flowing in only one direction, which was from a single source to the users. This fundamental characteristic is changing with the advent of decentralised generation.

The new situation calls for adapting the protection plan of the involved generating sets, and creates new constraints regarding transient stability of the units and respecting their operation range.

Addressing these new requirements and constraints implies using other than the traditional computer tools, which covered static analysis of the systems.

This article reviews the impact of electro-mechanical transients on the operation of distribution networks, and discusses the advantage of EUROSTAG simulation software aimed at ensuring optimal reliability of the systems, applying solutions that are compatible with the size of the systems. Emphasis will be put on the behaviour of the various criteria that can be used to adjust the decoupling protections.

The various aspects will be analysed on a typical example of a distribution system that includes several dispersed generating units.

WHY DYNAMIC-ANALYSIS TOOLS FOR DISTRIBUTION POWER SYSTEMS

The following aspects need to be addressed by means of simulation software that can take the electro-mechanical transients into account.

- Precise evaluation of the short-circuit currents at various points of the system. Detailed modelling of spinning power (induction motors or generators) makes it possible to determine the short-circuit values for adequate sizing of the breaking devices and correct adjustment of the protections.
- Transient stability analysis of the units, by defining the critical clearing times of electrical faults. This enables to verify the adequacy of the site’s protection plan and ensure unit tripping in case of loss of synchronism.
- The selected chooses for the decoupling protection, which has to rapidly disconnect the unit when the unit finds itself in a subsystem that is no longer connected to the supply grid. The protection must act quickly so that the subsystem may be re-supplied in case of auto-reclosing of the faulted components. Adjusting this protection on the basis of local values (voltage phase and module, frequency) is not easy. Indeed, various parameters affect the evolution of these values : the behaviour of the unit controls; the behaviour of the load, and particularly that of the induction motors; …
- In certain particular situations the dispersed generation means must be able to supply part of the distribution network although they are disconnected from the supply network. This implies that various elements must be examined such as the protection plan behaviour, the capabilities of the units to face load fluctuations, the possible activation of a load-shedding plan, … This particular point, which rather concerns industrial networks, is not discussed in the present article.

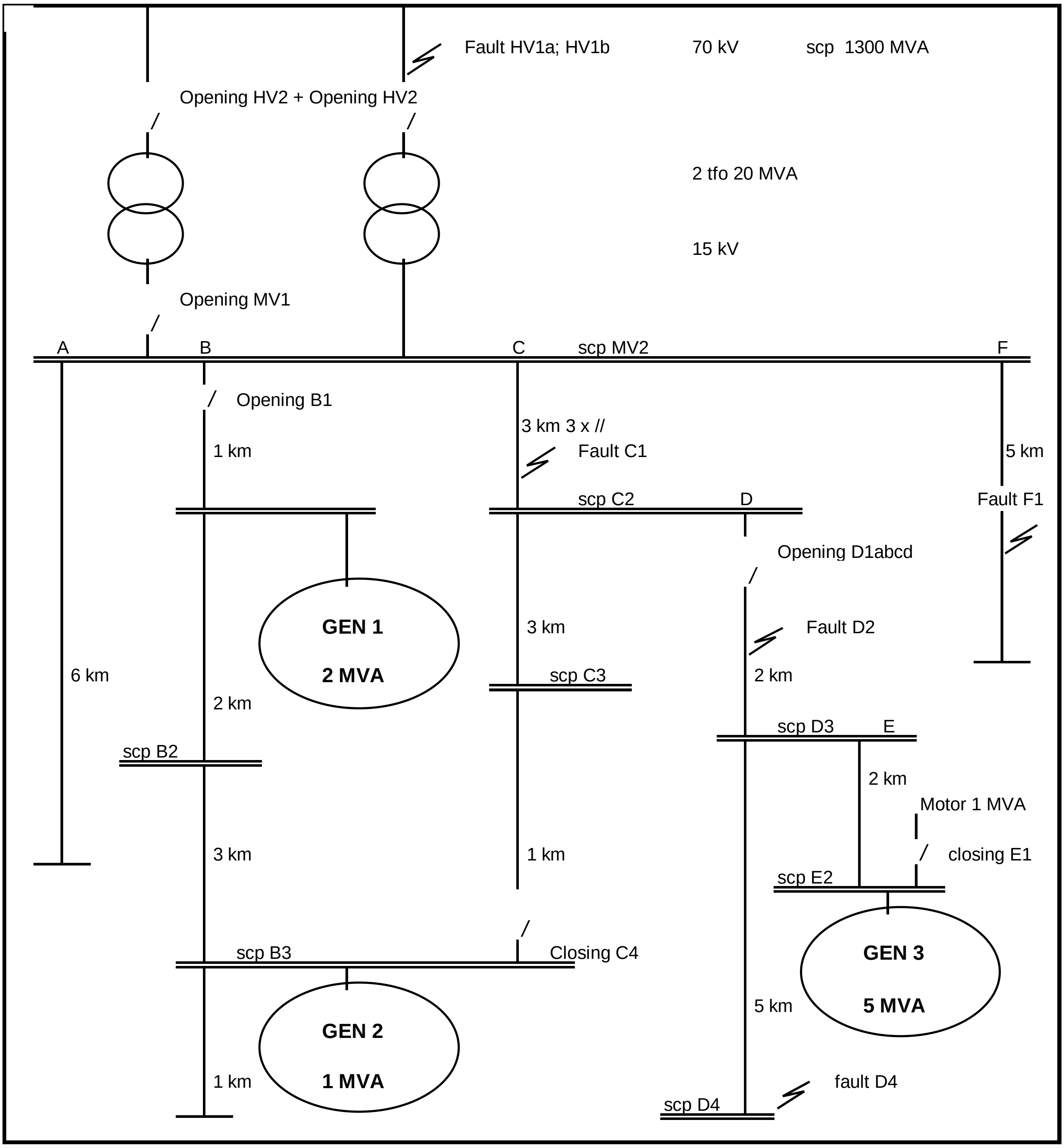

FIGURE 1

EUROSTAG program

General points

The presented analysis has been realised with the software EUROSTAG

EUROSTAG is a time simulation program developed by Tractebel and Electricité de France to study the transient, mid- and long term dynamics of large power systems [1], [2]. It uses the same type of component modelling whatever the type of disturbance, network behaviour or duration of the simulation, reproducing continuously both rapid and slow phenomena.

The differential and algebraic equations are solved simultaneously using a variable integration step. The size of the step changes automatically according to the actual behaviour of the system (generally from 1 ms to 100 s) in order to guarantee constant accuracy of the integration process. The truncation error is in fact calculated at each step to determine the exact step length required.

The program is able to reach any stabilized network state and can be used to analyze quasi-steady states. An interactive calculation of own values makes it possible to study the static stability of all steady states obtained during the simulations.

The Fortescue transformation allows any kind of computations related to unbalanced conditions (short-circuit, phase opening).

Modelling functions

EUROSTAG has extensive modelling capabilities in addition to the detailed models representing basic elements (alternators, induction motors). A graphic data entry program enables the user to code directly the block-diagram of the new model he wishes to define.

This graphic macro language is used to code models of voltage regulators, speed governors, turbines and systems such as boilers, SVC, static or dynamic loads, etc. A library of standard models is also available to the user.

EUROSTAG is also able to simulate automatic control systems. The moment at which these systems must act upon the network is determined by means of equations describing their operation. They are used, for example, to represent protective relays, the automatic tap changers of transformers or the automatic load shedding systems.

ANALYSIS ON A TYPICAL DISTRIBUTION NETWORK

The tested network is shown in schematic form in figure 1. This figure has been simplified to avoid an overly complicated diagram. Only those elements playing a role in the simulated scenarios are shown.

The network is fed primarily along a 70 kV interconnection with a short-circuit power of 1,300 MVA. The MV transformation (to 15 kV) is effected in two 20 MVA transformers with a short-circuit impedance of 10%. The MV network is grounded with a 1000 A limitation.
The analysed network load is 23 MW with a cos.phi of 0.95. Three dispersed generating units are connected to the MV network and provide 6.4 MW or 28% of the total load. Motors account for 35% of the load. The MV network consists chiefly of 240, 150 or 95 mm² aluminium cables.

SHORT-CIRCUIT POWER

The presence of dispersed generating facilities in the MV network has the effect of increasing the short-circuit power (called Scp afterwards). Three Scp values were calculated at different places on the network: the Scp at the time of the short-circuit, taking account of the Scp contribution of the motors and generators; the Scp 100 ms after the short-circuit, at which time the Scp contribution from the motors has disappeared but there is still a contribution from the generator transients; and the Scp calculated not taking the motors and dispersed generation into account.

TABLE I

Node in	Is in kA		
	at the time of the short-circuit Is-c max	100 ms after the short-circuit	without the contribution of motors and generators
MT2	16,3	12,4	11,76
B2	7,7	6,18	6,09
B3	4,2	3,5	3,42
C2	14	10,55	10,17
C3	8,6	6,7	6,65
D3	10,18	7,8	7,59
D4	3,55	2,97	2,91
E2	7,6	6,2	5,89

The results given in table I, show that it is useful to take into account the contribution from dispersed generation and the load mainly when estimating the value of the scp at the time of the short-circuit. This value, often overestimated by the standard calculation procedures, let to check the equipment rating adequacy.

DECOUPLING PROTECTION FOR DISPERSED GENERATION

The principle behind decoupling protection is to prevent the generator from continuing to supply the network when islanded or under abnormal voltage conditions. If that section of the network to which dispersed generating facilities are connected is no longer supplied or the voltage is no longer normal, it must be possible to immediately and automatically decouple the independent generating facilities from the network. The decoupling protection trips the system on the basis of 6 criteria:

- the frequency thresholds equals to 49.5 Hz and 50.5 Hz time undelayed; with a measurement time of 0.12 s.
- the upper minimum voltage with a time delay of 1.5 s
- the lower minimum voltage with a time delay of 0.2 s
- the presence of a zero sequence voltage with a time delay of 1.5 s
- maximum current with a time delayed of 3 s
- optionally, the undelayed detection of a vector shift of 7° on the 3 phases; with a measurement time of 0.06 s
- maximum voltage (not examined in this study)

Three additional criteria have also been taken into consideration:

– 7° vector shift locked by Umin 80% on the 3 phases
– the accepted frequency deviation decreased to ± 0.3 Hz
– frequency derivative df/dt (ROCOF) locked by ± 0.2 Hz, with a time delay of 0.1 s

PROTECTION TESTS

A generic decoupling protection has been introduced in EUROSTAG. Thanks it all the above criteria are concentrated in only one automatic control system.

Various network events, incidents or network operations are simulated. The full list of events is given in table II.

For each of these events, the reaction time of all decoupling protection criteria are examined for each dispersed generating unit.
The results of GEN 3, the most significant, are given in table III. The first 6 columns show the standard decoupling protection criteria. These correspond to the legal minimum Belgium. The last three columns give the reaction times for the additional criteria.
For generator GEN 3, the results are put into two categories. The first group is composed of those events that did not lead to the islanding out of the dispersed generation in question. These events should not cause tripping to occur. The second group contains the events that did island out the dispersed generation. These events should cause tripping. This tripping should ideally occur within 0.4 or 0.5 s, after which time the generator concerned will have lost synchronism in order to respect the equipment safety requirements.

The location of the different events is also given in fig. 1. Here, when the event is a fault it bears the label *Fault* together with the location in the network. When the event is a network operation it is labelled either *Opening* or *Closing*, together with the location of the operation in the network.

Islanding out after an operation is harder to detect than islanding out after a fault. In the former case the protection behaviour can only be influenced by the load variation. In the latter case the surge caused by the fault is a decisive factor and is a welcome addition to the load change. This is why various kinds of operation have been taken into consideration here.

TABLE II

INCIDENTS	
Fault HV1a	long three-phase fault, 300 ms, on the HV network
Fault HV1b	short three-phase fault, 80 ms, on the HV network
Fault C1	three-phase fault on the 3 wires of feeder C, causing feeder C to trip after 100 ms
Fault D2	single-phase fault on feeder D opening feeder D after 1 s.
Fault D4	distant three-phase fault on the MV network during 300 ms, on feeder D
Fault F1	transient single-phase fault on the MV network on feeder F

NETWORK OPERATIONS	
Opening HV2	opening the HV/MV transformer supply islands out the whole MV network
Opening MV1	tripping the feeder of a transformer causes a vector in the MV network
Opening B1	tripping feeder B1 islands out generators GEN 1 and GEN 2
Closing C4	closing the circuit causes a start of parallel on the MV network
Opening D1abcd +h	tripping feeder D islands out generator GEN 3. Indices a, b, c and d correspond to different active and reactive power deficits. The index +h corresponds to double inertia of the generator.
Closing E1	starting a high-powered engine on the MV network

For example, fig 2 shows how the voltage characteristics on GEN 3 change immediately following fault on D4. In the first graph, the voltage drops to 70% of its nominal value during 0.3 s. In the second graph, a 27° vector surge appears at the fault time. The third graph shows that the ± 0.5 Hz threshold has not been overtaken meanwhile it is not the case for the 0.3 Hz threshold. As indicated in the table III, an unwanted tripping caused by the vector shift criteria, locked or not, follows the event. It is also the case for the frequency variation when the tolerance decreases to ± 0.3 Hz.
In the case of fig 3 (opening D1b), the vector shift criterion doesn’t work.
Indeed the load collapse due to the voltage drop alters the active power deficit, this fact reduces the observed vector shift. On the other hand, the speed variation is high enough to be detected by the frequency criteria.

TABLE III

GEN 3	Standard decoupling criteria						Additional criteria		
	frequency ± 0,5 Hz 0,12 sec	Umin 80% 1,5 sec	Umin 50% 0,2 sec	Uo 1,5 s	I max 0,3 s	vector shift 7° 0,06 s	V surge 7° locked Umin 80% 0,2 s	frequency ± 0,3 Hz 0,12 s	df/dt locked frequency 0,1 s
NON-ISLANDING SCENARIOS FOR GEN 3									
Fault D4						0,06 s	0,2 s	0,43 s	
Fault HV1a	0,19 s		0,2s		0,3 s	0,06 s	0,2 s	0,17 s	0,13 s
Fault F1									
Fault HV1b						0,06 s			
Opening MV1						0,09 s			
Closing C4									
Closing E1									
Opening B1									
ISLANDING SCENARIOS FOR GEN 3									
Fault C1	0,18 s	1,5 s	0,2 s		0,3 s	0,06 s	0,2 s	0,16 s	0,13 s
Fault D2	2,19 s	5,34 s	7,6 s	1,5 s	4,91 s	7,9 s	7,9 s	1,47 s	4 s
Opening D1a	2,32 s	5,27 s	7,46 s		4,86 s	7,76 s	7,76 s	1,63 s	1,44 s
Opening D1b	0,33 s	3,11 s	3,54 s		3,28 s	3,9 s	3,9 s	0,26 s	0,2 s
Opening D1b (1)	0,33 s							0,26 s	0,2 s
Opening D1c	0,51 s	1,57 s	0,84 s		0,6 s	1 s	1 s	0,44 s	0,37 s
Opening D1d	0,24 s					0,11 s		0,2 s	0,16 s
Opening D1d +h	0,35 s				0,33 s	0,11 s		0,25 s	0,19 s
Opening HV2	0,16 s	1,57 s	0,34 s		0,3 s	0,06 s	0,27	0,15 s	0,12 s

(1) without a cos phi regulation on GEN 3

ANALYSIS OF RESULTS

The results presented in table III highlight the fact that the best criteria are the frequency and the derivative frequency ones.

Uo criterion can be useful for revealing islanding resulting from a long single-phase short-circuit. The Umin criteria provide backup and guarantee the voltage quality. They are also useful when a voltage dip provokes the deactivation of the frequency or vector shift criteria. The Imax criterion also plays a backup role.

Vector surge does not always live up to expectations. It leads to unwanted tripping, while locking by voltage considerably reduces unwanted actions but at the same time is detrimental for the criterion's behaviour when the system is islanded out.

Frequency criterion guarantees a good selectivity. The only action occurred with a non-islanding scenario, is the fault HV1a in which moreover GEN 3 loses the synchronism. This action is therefore beneficial.

The simulations also show that the df/dt criterion improves the speed reaction without decreasing the selectivity. Besides, these criterion characteristics do not request an accurate adjustment of its threshold.

CONCLUSIONS

Connection of dispersed generating units to distribution networks results in new operational constraints in these networks.

EUROSTAG software enables to address these constraints at both the design and operation stages of these networks in order to achieve optimal reliability and security.

It further enables to check on real case,the selected choses for the decoupling protection, which adjustment is reputedly delicate. The analysis of the various criteria to be used for evaluating this protection on a typical MV-system demonstrates that frequency and derivative frequency criteria supply better results than a vector shift criterion with or without interlocking.

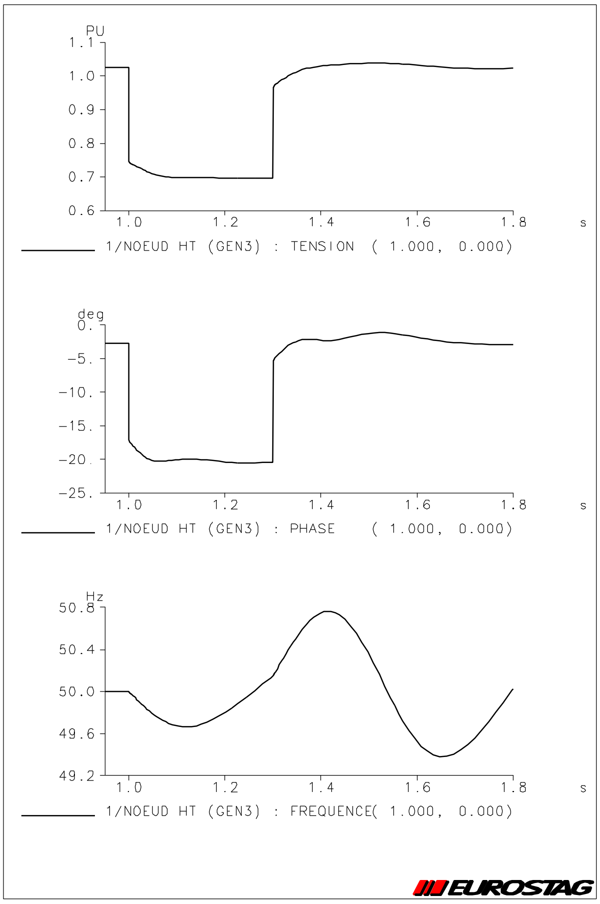

FIGURE 2 : Effect of fault D4 on GEN 3

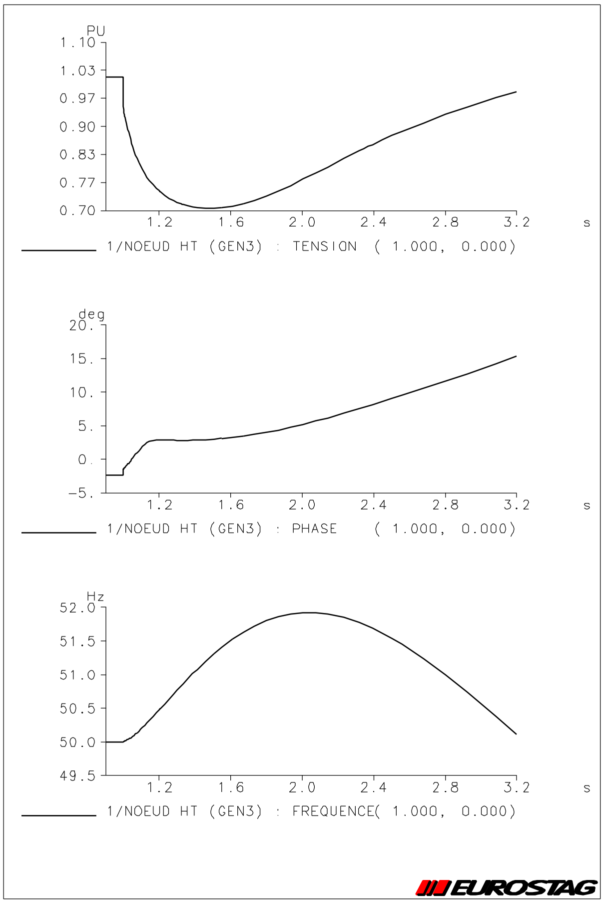

FIGURE 3 : Effect of opening D1b on GEN 3, without a cos phi regulation on GEN 3

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