LIMITING THE DG INSERTION: A DETERMINISTIC CRITERION

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INTRODUCTION

The dependence of present societies on the electricity supply does that the electric power system (EPS) is one of the critical points in the normal life and defence of a country. The absence of electricity provokes problems for daily life and so, EPS constitutes a critical infrastructure for societies .

The international agreements to reduce the Greenhouse gazes emissions and new rules such as European directives to increase the renewable energy sources have promoted the creation of national plans to install new DG resources. These new plans fix a tendency to integrate a high quantity of new DG sources. The special dynamic performances ofDG make that new considerations and criteria should be taken into account in the EPS control and planning in order to guarantee a suitable operation and, therefore, the system's robustness.

The article gives an overview of the different impacts and the influence of DG in the EPS operation. The amount of DG insertion in the EPS should be limited to prevent catastrophic consequences in real-time operation. Thus, a deterministic criterion is proposed to be taken into account in the study of the system robustness. The main conclusions of the article are illustrated with EUROSTAG simulations based on a European-adapted 39buses network (adaptation of the IEEE New England 39 buses to European data).

The works included in the article are integrated in the CRISP[1] project.

DG INSERTION IN EPS

The generation of energy is normally carried out in the transmission system by means of huge power plants (1000-1300 MW) based on thermal, nuclear or hydro energy. But, this is not the unique power injection in the electric networks. There are other generation injections, called DG, e.g. CHP (Combined Heat and Power) generators and small local independent producers at the sub-transmission system, or the small dispersed generators at the distribution system.

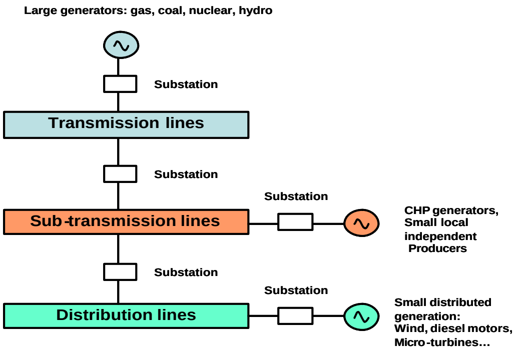

Figure.1.-DG insertion in Electric Power Systems

The voltage level for the DG connection (sub-transmission or distribution) depends essentially on rated power of generators and the local network characteristics. The liberalisation of the energy market has favoured the apparition of these new DG producers.

DG units are based on conventional and non-conventional energies. The conventional DG corresponds to micro-turbine, CHP, fuel cells, Diesels or storage among others. The non-conventional energies refer to the renewable sources such as wind energy, hydro or PV. Renewable sources are widely seen as a relevant tool to comply the obligations coming from the Kyoto protocol. The estimation of new DG based on RES (Renewable Energy Source) is shown in figure 2 by ETSO (European Transmission System Operators) data [1] for the percentage of the total capacity which is based on renewable energies. In this figure 2, it is also shown the tendency to new DG installations. Hydro power is the renewable energy source that contributes with the biggest share to the renewable generation in Europe.

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However, the present plans to install DG-RES are concentrated in the off-shore and on-shore wind power potential. The exploitation of the wind energy is now expected to be the main driver for reaching the targeted RES development in the future.

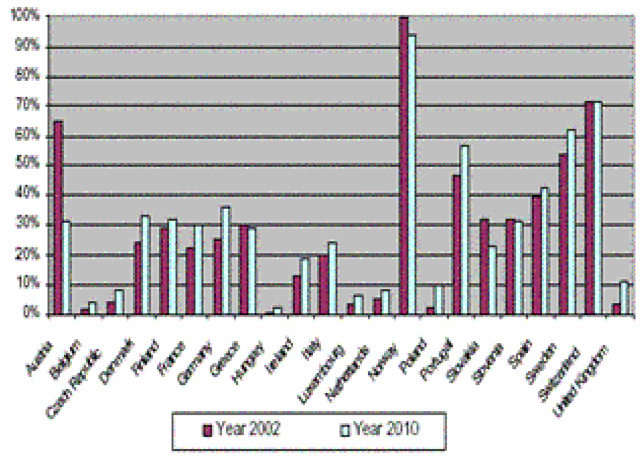

Figure.2.-ETSO data about the DG-RES capacity

DG can cause some impacts on the EPS. These impacts could be classified in two different groups: impacts on the distribution system and impacts on the transmission system. The main impacts that DG could cause on the distribution system are the next ones [2], [3]:

- Impacts on the energy direction: traditionally the EPS was designed for a top-down energy flow but the DG implies a bottom-up energy flow. Thus, it is possible that the energy is injected into the sub-transmission and transmission systems
- Impacts on the protections (setting points, selectivity and bad operation of protection).
- Impacts on voltage profile.
- Impacts on stability.
- Impacts on power quality (harmonics, sags, surges and deeps).
- Impacts on the planning, exploitation and observability of distribution networks: the distribution networks were not designed to insert the DG in a high amount. So, it is probable that some changes will take place in its exploitation and observability [4], [5]. The DG should be controlled by the utilities and DSO (Distribution System Operators); it will mean an increase of SCADA data. It is also possible that the traditional radial architecture will be changed into a meshed one.
- Economic impact on the energy markets: associations and agreements of DG producers to propose bids in energy markets (day ahead, balancing or ancillary services markets).

On the other hand, the main problems that a large amount of DG insertion could cause to the transmission system deal with prevision of reserves, operation in real-time and emergency strategies. The main impacts of a high amount of DG on the transmission system can be summarized as follows:

- Risk of congestion in specific areas.
- Intermittence problems [6]: uncertainty in the power injection (location and amount).
- Change of real-time exploitation margins.
- Change of the real-time exploitation strategies (DG as a base power because ecologic-friendly energy).
- Apparition of unexpected reactive power flows in the transmission system (flows in the lines down to the natural power).
- Closure of centralised power plants because economic and polluting reasons.
- Lack of DG sources caused by unforecasted weather conditions or by technical reasons (disconnection protection).

DETERMINISTIC CRITERION

The EPS are interconnected in order to increase the support between national systems and so, ensure a better quality of supply to the customers. TSO (transmission system operators) take some security criteria (e.g. (n-1) criterion) in order to guarantee a suitable system's robustness. Some examples of adequacy criteria are the following ones [7], [8]:

- Probabilistic
  -LOLF (loss of load frequency) (unit: failures/year)
  -LOLP (loss of load probability): a loss of load will occur when the system load exceeds the generating capacity in service. The overall probability that the load demand will not be met is called the loss of load probability or LOLP (unit: dimensionless)
  -LOEP (loss of energy probability) or LOEE (loss of energy expectation): the loss of energy method is a variation of the loss of load method. Here the measure of interest is the expected non-served energy split by the total energy demand over a period of time.
  -EUE (Expected Unserved Energy).

- Deterministic (working rules coming from experience):
  -Percentage reserve: it consists on defining a reserve for each system, representative ranges are 10-30% of peak demand in installed capacity and 2-10%in operation. This criterion compares the adequacy of reserve requirements in totally different systems on the sole basis of their peak load.
  -Another widely used criterion calls for a reserve equivalent to the capacity of the largest unit on the system plus a fixed percentage of the dispatched capacity.

The article proposes a new deterministic criterion that should be taken into account in the control of the system it consists on the consideration of the DG amount insertion compared to the system action in case of emergency. The system should stand high variations on the DG production: these DG variations of injected power could represent, in some cases and in future perspectives, a bigger power than the biggest

unit in national systems (and so, questioning actual common generation adequacy working rules). They could be caused by weather conditions (e.g. windmills disconnections or errors in forecasted energy) or by (Initial event – DG tripping) caused by the operation of the DG disconnection protection. As systems are interconnected and synchronised, these variations are not reduced to national power plants and the combined apparition of such events could lead the system to resulting blackouts.
An index, that defines the criterion, can be introduced; it is the frequency deviation (FD) index, which evaluates the dynamic responses of the system in terms of active power balance (see equation (1)).

$$(FD) = \frac{[(PR)+(IL)]}{[ALEA + (DG_1)+(DG_2)]} \qquad (1)$$

where PR is the primary reserve (MW), IL is the amount of interruptible loads or load shedding (MW) planned up to 48.5 Hz, DG_1 (MW) is the DG with instantaneous or very quick (100ms) disconnection protection, DG_2 (MW) is the DG with temporized disconnection protection at 49.5 Hz and ALEA is the maximal load variation or generation loss forecast by the operator (the generators included in ALEA should not be included in DG_1 and DG_2). ALEA can be also a short-circuit or event that provokes that the system arrives to the setting points of the disconnection protection before 49 Hz and 0.85 Un. DG influence in the system is given through FD index, notably in terms of disconnection protection and lack of sources.

FD gives a good view of the system and quantifies the risk of the system in case of an excessive DG insertion. If FD < 1, the operator should place an alert because the DG insertion could endanger the whole system in case of major contingences. On other hand, if FD > 1, the system is stable in case of appearance of contingences (ALEA). Thus, the events consequences on frequency are compared to primary reserve and first load sheddings, which are supporting tools of the system in case of emergency (to study the whole system robustness and take into account static and dynamic system indices, special indices can be used [9])

The problems of the disconnection protection could be seen during the last blackout in Italy [10]. Future changes in the legislation are in progress to adequate the protection and improve the DG reaction in case of disturbances [11].

On other hand, DG variations are expected to increase tertiary reserves in order to integrate light and medium DG variations, but if the deterministic criterion (high variation) is taken into account primary and secondary reserves should be increased in order to stand unexpected events (including the DG variations).

STUDY CASE

The study of the deterministic criterion was carried out using a study case: the IDEA_CRISP_39buses network (see figure 3) that is an adaptation of the IEEE New England 39 buses system. The architecture of this IEEE network is mostly kept. However, the parameters of its different elements were adapted to normal European data. So, the transmission system is considered at 400 kV and the generators (Gen 1 to Gen10) produce the energy at 20 kV. The installed power is 9085 MVA and it is shared in three different types of generators: 4 thermal units of 1000 MVA each one (GEN4, GEN6, GEN8 and GEN9), 3 nuclear units of 1080 MVA each one (GEN1, GEN2 and GEN3) and 3 hydro units of 615 MVA each one (GEN5, GEN7 and GEN10). The total consumption is 6141.6 MW/ 1470.9 MVAr split in 18 loads. The load model associated with the consumption is the impedance model (a quadratic variation with the voltage). The generators regulations are of two types: a voltage regulation and a frequency regulation. The voltage regulator is the IEEE voltage regulator type A [12]. The frequency regulator is a torque regulation with a speed droop of 4% [13].

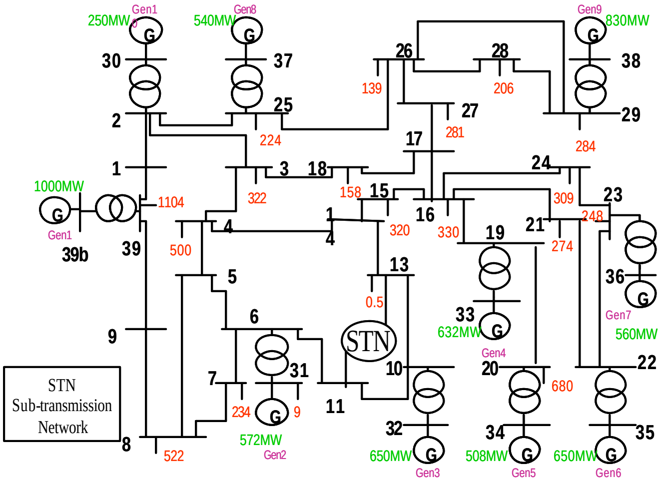

Figure. 3.-Study case architecture without DG insertion (green: generators active power in MW; red: load consumed active power in MW)

The study case includes, as well, a 63 kV sub-transmission loop and 2 real French 20 kV distribution networks (STN) and several distributed resources (DR) by means of equivalent synchronous machines injecting 100 MW in the transmission system to build different DG insertion cases: 10%, 20%, 30%,40%, 50% and 60%.

RESULTS FROM SIMULATIONS

Different scenarios of DG behavior were simulated with different amount of DG insertion in the system in order to apply the index and define an appropriate amount of DG insertion in the chosen test case. Some of the different studied scenarios were the following ones [14]:

- Scenario 1: Instantaneous disconnection protection.
- Scenario 2: DG without problems of disconnection protection.

Scenario 1: Instantaneous disconnection protection

The appearance of a short-circuit at the transmission level is an event which can provoke the propagation of a voltage deep and frequency deviations in the system and so, the disconnection of generators. DG should be limited in order not to shed loads after a fault in a transmission line. One should take into account that load shedding is an emergency tool and if the load shedding is used (at 49 Hz) by a first short-circuit; the system could remain in a bad operating point to face latter events.

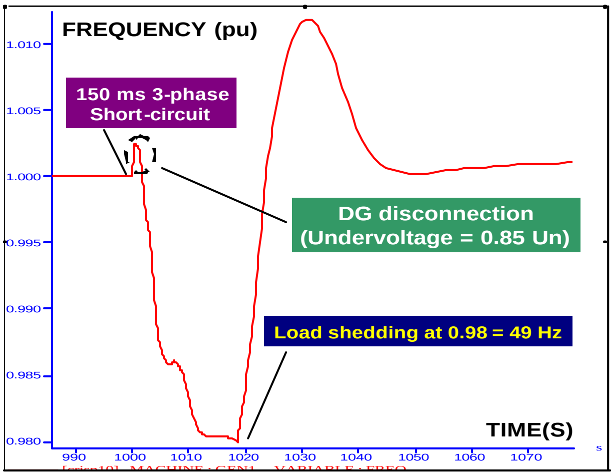

Figure. 4.-Dynamic reaction of the study case (with 10%DG instantaneous protection) faced to a 150 ms 3-phases short-circuit

Therefore, in this case, a slightly lower level than the primary reserve, it is the appropriate amount of DG insertion (instantaneous disconnection protection) regarding adequacy (ability of the system to supply the aggregated demand).

Scenario 2: DG without problems of disconnection protection

In this scenario 2, DG is considered without problems of disconnection protection, what it means that DG has a dynamic behavior equivalent to centralized power plants in the disconnection protection. This assumption will allow us to analyze the system action when faced to problems derived from the loss of generation. This loss of sources could appear e.g. with a high wind turbines insertion when wind is strong enough that causes the turbines cut-out disconnection.
The appropriate DG insertion is fixed by the resources of the system (active and reactive power) and the dynamic behavior of the system when faced to the chosen contingencies (transient stability and no loss of synchronism). The high degree DG insertion makes that some centralized generators could be closed or stopped. So, the operators should be able to guarantee reserves and a good voltage plan with the existent generators. The maximal amount of DG insertion is placed here around 50% of the total production. For higher amount of DG insertion such as 60%, stability problems were found in the system.

TABLE 1- Results in the 50%DG insertion without disconnection protection problems

Events	System saved by	PR (MW)	IL = LS (49 Hz) (MW)	FD (for ALEA = Event)
Loss of DG < PR	PR	731	928.35	> 2.27
Loss of DG = PR	PR	731	928.35	2.27
Loss of 10%DG (600 MW)	PR + LS (49.5 Hz)	731	928.35	2.76
Loss of 20%DG (1200 MW)	PR + LS (49.5 Hz)	731	928.35	1.38
Loss of 30%DG (1800 MW)	PR + LS (49.5 Hz) + LS (49 Hz)	731	928.35	0.92
Loss of 40%DG (2400 MW)	PR + LS (49.5 Hz) + LS (49 Hz)	731	928.35	0.69
Loss of 50%DG (3000 MW)	PR + LS (49.5 Hz) + LS (49 Hz)+ LS (48.5 Hz)	731	928.35	0.55

The limit, in this case, is the system's security (ability of the system to stand disturbances and ensure a good real-time control). The system should be able to share the reserves between the existent generators and stand the lack of a big part of DG sources (errors in forecast, disconnection by wind gusts, weather forecast of strong winds and apparition of storms). An appropriate amount of DG insertion from this deterministic criterion point of view is the one which gives a FD value around 1 and therefore, they do not give rise to important load shedding in case of this DG loss.

CONCLUSIONS

The article has presented a view about the DG insertion, its possible impacts and influences. The special dynamics of DG sources (disconnection protection, intermittence problems) make them especially negative if some disturbances appear.

In order to limit the DG insertion and the negative influence of DG during EPS operation, the paper has proposed a deterministic criterion to analyse the system operation. This criterion is based on a comparison of DG insertion with the very quick emergency strategy (primary reserve and first load shedding step). The criterion is introduced through an index (FD). It was applied in a study case and several contingencies were analysed with different DG behaviour. As conclusion, DG insertion with special dynamics, in disconnection protection or with problems derived from the intermittence, should be limited or changes in the emergency strategy should be considered in order to avoid negative effects on the system. Obligations that TSOs impose to DG producers should be enlarged in the future years in order to adequate the DG behaviour in emergencies.

One economical paradox could appear in the next years after the market deregulation: EPS could need additional reserves for secure and adequate operation with high amounts of DG insertion. Thus, one can see how, in the worldwide, the possibility of load shedding is proposed to customers with economic incentives [15].

The increase of primary reserves would limit the benefits of some actors to integrate other actors, because primary reserve is an obligation and not a service for generators up to a defined level [16]; so, compensations (for extra primary reserve and load shedding capability) could be reviewed in a free concurrency market to those actors that stand the system and TSOs to manage the actor's integration.

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