Explanatory note for power output versus frequency

EU Network Code Requirements for Generators (as per June 12, 2012), Art. 8.1.e):

1. Current Requirement of Art. 8.1.e):

b) With regard to underfrequency maximum power capability reduction for some generation technologies, some synchronous generation technologies deliver falling mechanical power with falling frequency. The TSO shall define a Maximum Capacity with falling frequency. The value chosen by the TSO shall be within the boundaries of:

- Below 49 Hz falling up to a maximum reduction rate of 2 % of maximum capability per 1 Hz frequency drop below 49 Hz.
- 49.5 Hz up to a maximum reduction rate of 10 % of Maximum Capacity per 1 Hz frequency drop below 49.5 Hz.

Acceptance of this reduction is limited to a selection of affected generation technologies decided by the Relevant TSO pursuant to Article 4(3).

A graphical representation and a comparison with some current national requirements are given in Fig. 1:

These requirements shall ensure that under extremely disturbed grid conditions, with a lack of generation exceeding the design conditions for normal frequency response, the situation is not getting worse due to a further output reduction of the generation facilities connected to the grid and operated at full output. It is at the same time common understanding that the prevailing objective in such case is to remain connected to the grid in order to stabilize it by inertia, as well as by active and reactive output.

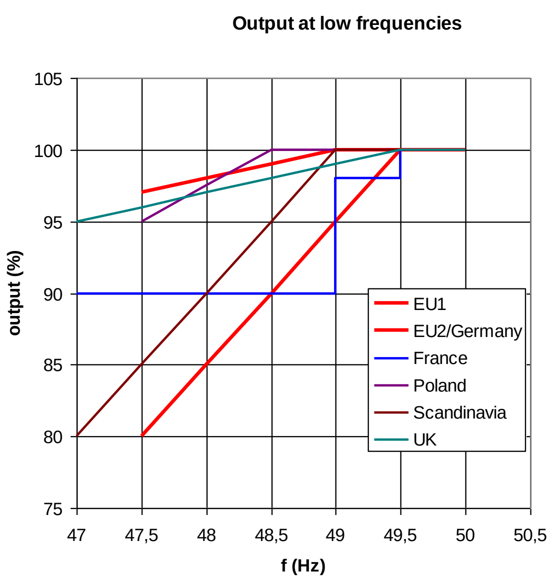


Figure 1 : Requirements

It has to be noted that in UK the current requirement is limited to an ambient temperature of 25°C and for CCGT modules to a time duration of 5 min in case frequency is below 48,8 Hz.

There exist furthermore some dynamic short term requirements (e.g. Germany, Austria and Hungary) to keep the plant on nominal output even if the frequency falls to 49 Hz (resp. 48 Hz in Austria) for a limited time (approx. 30 s).

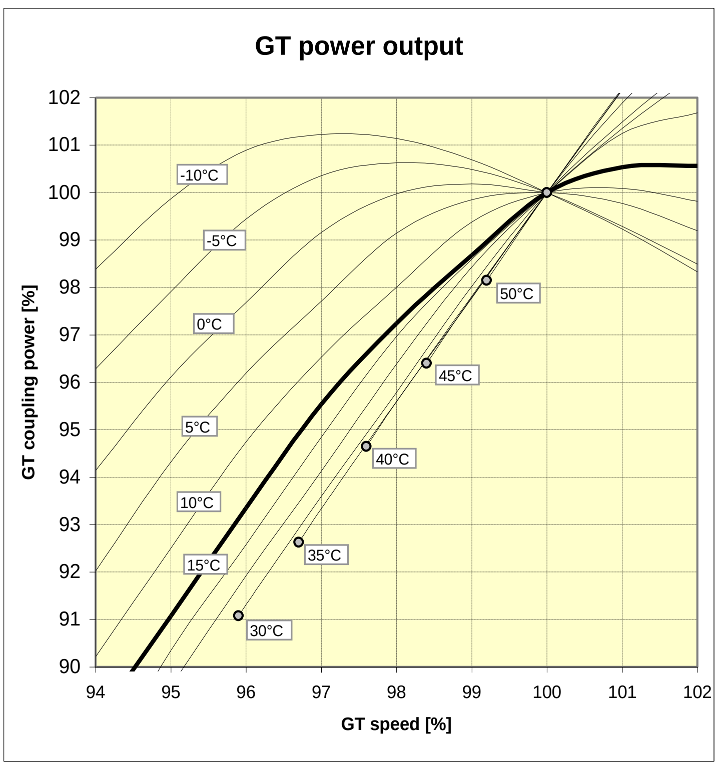
This requirement therefore applies

- if a generating unit is operated at its current maximum output (which is depending on ambient conditions) without intrinsic output headroom
- under extremely disturbed conditions with a large drop of frequency when the system is not far from a total black out.

2. Physical behaviour of a gas turbine at low frequencies

In contrast to e.g. a coal fired power plant, where steam generation is independent of the frequency (the small effect in the steam turbine at lower frequencies is negligible), a gas turbine shows a reduced air mass flow as a direct and immediate consequence of the decreasing grid frequency and hence the turbine rotational speed.
In addition, in order to have stable combustion conditions and not to risk any combustion disturbance with a consequent trip, the turbine outlet temperature is kept constant, adapting the fuel mass flow to the reduced air mass flow.
Both effects lead to a nearly immediate output reduction of the turbine in parallel to the frequency drop.
This behavior is highly nonlinear, and also strongly depends on the ambient conditions. If two parameters (in this case ambient temperature and frequency) deviate largely from design conditions, the effect is overlaid.

The following figure shows a typical behaviour of a utility size gas turbine (detail values depend on the individual machine), without any additional compensation features and without consideration of the Combined Cycle effect which reduces the output drop by approximately one third due to the virtually constant output of the steam turbine.



Additionally to the compressor thermodynamics, operation of the compressor is limited by the protection scheme against compressor pumping, which has to be avoided in any case and therefore limits the underfrequency operation at very high ambient temperatures.

3. Handling of the requirement in the past

The most stringent requirement in Europe to be applied to GT based plants so far can be found in UK (CC 6.3.3. of the Grid Code). It is only where also specific tests are defined which shall demonstrate compliance with the requirement.
It is obvious that such tests cannot take place under real conditions, because the real grid frequency cannot be reduced as required and also the real reduction of base load output of the plant cannot be seen. The test therefore just allows to show the possible activation of countermeasures, triggered by a suitable signal (e.g. simulated frequency decrease), and possibly the effect of some output increase.

CCGTs installed in UK during the past years had to comply with this requirement and therefore the manufacturers have been developing technical measures to compensate the physical output drop.
Despite the fact that manufacturers have been mentioning this issue in other countries several times for specific projects, there has been and still is no clear statement and definition under which conditions compliance has to be ensured and how it should be demonstrated.

Only in the last very few years the focus of the TSOs has been shifting more towards disturbed conditions, but in our perception only in countries with a significant fraction of GT based generation this is being seen as a relevant topic.

The principles of technical countermeasures range from increasing the flame temperature (i.e. increasing the enthalpy difference available in the turbine), to increasing the mass flow by further opening the inlet guide vanes (higher air mass flow with consequent increase of fuel gas) or injecting steam or water to the compressor (combined effect of total mass flow increase and cooling). Often one measure is not sufficient and a suitable combination has to be foreseen.

4. Concerns about the current NC RfG requirement

Activation time

Neither in the UK Grid Code nor in other national regulations in Europe (except the additional more stringent dynamic requirement as mentioned in Chapter 2), nor in the NC RfG, there is a definition within which time frame such possible countermeasures have to be activated and have to reach the required compensation level.
In the view of network stability, it can be expected that the activation should take place within very few seconds, in particular in case of fast frequency drops. However, for some countermeasures (in particular temperature increase, activation of water or steam injection through specific additional systems) reaching the required output level and at the same time ensuring stable operation takes more than several seconds and therefore will be too late for the desired effect. Countermeasures with a very short or negligible activation time are currently not available.

Ambient temperature limitation

The current limitation in UK to 25°C ambient temperature is beneficial regarding the capability of compliance for the turbine (see Chapter 2). However no rationale can be seen why the grid is not needing the capability above 25°C with the same strictness at it is below 25°C. In the NC RfG there is no such limitation, which is reasonable from grid stability point of view, but it makes compliance much more difficult.

Reliability of countermeasures, risk of trip

As mentioned, many of the additional measures are being installed only for the purpose of compliance with the requirement and are not used under normal operation. Additionally, as also already mentioned, the test of the system is done only once and not under realistic conditions.
Therefore manufacturers cannot absolutely ensure the correct function and effectivity in case of a real frequency drop.
Even more, such extremely disturbed frequency conditions are not easy to be handled and controlled by a complex system like a gas turbine even without additional measures. Therefore there is a not negligible risk of causing a trip of the machine by activation of such system exactly in that moment when all efforts should focus on keeping generation reliably connected to the grid.

Unfortunately there is absolutely no statistical data available about reliability during such incidents (they are extremely rare), but with the knowledge about the sensitivity of gas turbine combution systems regarding disturbances we see quite a probability to cause a trip, being then possibly the reason for the final black out of the system.

Cost of compliance with requirement on generation side

The existing additional systems and measures to compensate the output drop (but with the above mentioned limitations!) require additional hardware with a certain investment volume.
Any further development in this area will be still only an additional measure to compensate a physical behaviour of a very valuable grid component with the same principle restrictions as mentioned above.
As a theoretical alternative, GT based power plants might be obliged to limit their output all the time in normal operation to a value far below their current maximum output in order to have a reliable headroom for compliance with the requirement for a hypothetical situation which possible never occurs. It is obvious that the cost of this theoretical option, considering the necessary flexibility and efficiency of CCGTs, cannot be acceptable by no side.

5. Suggested amendment of the NC RfG

In order to maintain the system safely in operation under disturbed frequency conditions, we recommend considering an alternative approach:
The major objective of remain connected to the grid should prevail for power plants. The expected behaviour of specific power plants is known and can be disclosed and considered for network simulations. The summarized output drop of the connected plants will cause the frequency to drop with a predictable rate, which is more accurate in case the real behaviour of the plants is incorporated. This can be taken into account in measures on network side, e.g. for implementation into demand disconnection schemes.

Therefore we recommend amending the requirement in Art 8.1.e):as follows:

With regard to underfrequency maximum power capability reduction for some generation technologies, some synchronous generation technologies **inherently** deliver falling mechanical power with falling frequency. **For grid stability reasons, being the main objective under such conditions, the generating unit rather should stay connected than bearing the risk of a total trip due to the necessary fast activation of power compensation measures. The generating unit owner provides data to the relevant TSO about the expected output behaviour with frequency and other relevant parameters (e.g. ambient temperature).**
Acceptance of this reduction is limited to a selection of affected generation technologies defined by the Relevant TSO while respecting the provisions of Article 4(3).

Brussels, 22 November 2012

Identification Number in the register of interest representatives: 75093131694-63

EUTurbines – European Association of Gas and Steam Turbine Manufacturers
Blvd. A. Reyers 80
1030 Brussels, Belgium
www.euturbines.eu