New method for the protection of gas turbines against overload and overspeed
Protection of gas turbines against overload and overspeed

1. Summary

Gas turbine generator sets, in particular with aeroderivative gas turbines, are sensitive to electrical fault events that can damage the gasturbine.

A mechanical protection i.e. with a torque limiting coupling is in many cases not possible because of the overspeeding of the turbine after the release of the coupling.

A new method for protection of gas turbines against overtorques and overspeeds is described below. The overspeed limitation is achieved through the incorporation of a hydrodynamic coupling, acting as a brake.

2. Background

A gas turbine generator set, pic. 1 normally consists of three major mechanical components which are a gas turbine, a gearbox and a generator.

These components are connected with couplings which besides transmitting the torque also must be able to cope with the misalignments and the displacements caused a. o. by the temperature gradients in the system.

The generators operate at standard speeds which are 1500 (1800) rpm or 3000 (3600) rpm.

The gas turbine speed differs with the individual turbine design from 3600 to 20000 rpm.

A gearbox that reduces speed is required in practically all generator set designs. The gear ratio can be as high as 12 times and different types of gearboxes are used.

3. Aeroderivative gas turbines

The aeroderivative gas turbines are based on volume produced airplane engines with only minor design modifications. The similarity in design and components makes the production and service of this type of turbines very cost effective.

The lightweight design however also makes the turbines more sensitive to the overloads that can appear when there is a malfunction in the system.

4. Fault Conditions

From a power transmission point of view, the drive during normal running conditions can be considered as very smooth with small variations in the torque. The overtorques that can appear, and which have to be considered in designing the system, are rare failure events.

Disregarding the pure mechanical failures the potential source for overtorques is the generator. Electrical fault conditions in the generator can produce big overtorques which are spread backwards in the system and might expose the turbine, the gearbox and the power transmission components to excessive torque.

The electric fault events are basically:
- Malsynchronisation
- Short circuit

Both events involve torque peaks at the generator output shaft of a magnitude ten times fullload torque (10xF.L.T). The peaks are of short duration and the torque is pulsating with the frequency of the generated current. Malsynchronisation only gives few torque peaks while in a short circuit situation the pulsation of the torque can go on for some seconds.

The nature and exact size of the torque peaks are well defined and normally known by the generator manufacturer.

How the torque peaks are transmitted backwards through the system is governed a. o. by the inertia and the stiffness of the components involved.

The situation is complex and a dynamic analysis of the torque fault conditions is normally required for determination of the torque that reaches the gas turbine.
5. Torque limiting requirements

The turbine itself, which also is the most costly item, is in many cases the weakest link which has to be protected. The requirement for limiting the torque can in many cases be difficult. As examples both the Allison 501-KB7 and GE:s LM 6000 need a protection at approx. 2-2.5 x F.L.T in certain configurations.

Compared to most other drives protected with torque limiting couplings the relation between the requested torque limit and the F.L.T is unusually small.

Few coupling types are suitable for working under such conditions as i.e. discussed in ref (1) where in particular the inadequacy of the shearpin coupling in such situations is detailed.

6. Safeset couplings

The basic design principle of the Safeset® coupling is to transmit the torque through a frictional joint which torque capacity is controlled by hydraulic pressure. Such a coupling connecting a gear to a shaft is shown in pic. 2.

If the coupling is exposed to a higher torque than it can transmit over the frictional joint it will slip there. By the relative movement in this slippage a valve (shear tube) is cut open (by the shear ring) so the hydraulic pressure, the contact pressure and consequently the transmitted torque drops down to zero. The drop in torque occurs in a few milliseconds.

The general features of the Safeset® coupling as well as standard designs are desired in ref (2).

The Safeset® coupling has some basic advantages that has made it an attractive solution in certain gas turbine generator set applications.

- The torque limit is not influenced by high fatigue and remains practically unchanged also after a big number of load cycles, (ref. 3). The coupling will thus not release unnecessarily.
- The torque limit is adjustable and can be set at low levels, i.e. 1.4 - 1.6 x F.L.T and thereby protect components which have to operate close to their limits.
- The resetting of the coupling after release is quick and reliable so the downtime of the unit is minimized.

Typical applications, outside the power generation field are very highly loaded steel mill drives, pump drives in the chemical industry etc. where the hourly cost for downtime can be extremely high.
7. Overspeed and overspeed limits

When a gasturbine is mechanically disconnected from the workload and inertia of the generator it will momentarily increase speed.

The magnitude of the speed increase is controlled by the residual energy in the system, i.e. the amount of fuel that is available and how it flames out.

The overspeeding is also controlled by the inertia that is accelerated by the residual energy. Thereby there is a significant influence from where in the drive train the mechanical disconnection takes place.

If the separation is made between the gearbox and the generator the overspeeding gasturbine will have to accelerate not only its own inertia but also the inertia of the gearbox, which will result in a lower peak speed.

Speed is a critical design factor for a gas turbine and any overspeeding requires certain actions depending on how much the speed is exceeded.

Such actions could be:
- Inspection of the turbine
- Removal and complete disassembly

For the operation and for reducing the hazards it is important to reduce the overspeeding, and this can be done by including a hydrodynamic coupling in the drive train.

The requirements on the turbo coupling are limited by letting the coupling rotate at speed and only react on the speed difference between gas turbine and generator that is developing.

The braking torque is thus acting towards the relatively big inertia of the generator.

8. The hydrodynamic principle

The torque transmission behaviour of a hydrodynamic coupling (turbo coupling) is dependent mainly on the following factors.

Geometry:
- Profile design, diameter \( d_p \)

Operating fluid:
- Density \( \rho \), fill level, viscosity \( \nu \)

Operating conditions:
- Input speed \( \omega_p \)
- speed ratio (slip) \( \nu \)
- acceleration

The torque transmission behaviour of the turbo coupling can be described with the following formula (ref 4).

\[
T = \lambda \cdot \rho \cdot d_p^5 \cdot \omega_p^2
\]

The performance coefficient \( \lambda \) is dependent on fill level, speed ratio (slip’s) and the profile design.

Typical \( \lambda \) - slip curves for Voith Turbo couplings with various filling levels are shown on picture 3.

Two main features of the hydrodynamic coupling are the torsional separation and damping. (ref 5).

Input and output speeds or torque fluctuations are dampened or completely separated from input to output side, depending on the frequency.

These features have a positive effect in all applications in respect of the dynamic behaviour of the complete system. This will result in lower stressing of component parts and reduced stimulation.

Different applications require specific hydrodynamic coupling designs.

For example:
- Constant fill coupling: Soft start of electric motors
- Torque limitation on the driven machine
- Variable speed coupling: Control of driven machine speed.
- Clutch-type coupling: Separating driver and driven machine.

Specific coupling and profile designs have been developed to meet the various requirements. (ref 6).

![Typical slip curves for various filling levels.](image)
As described in chapter 7 the residual energy in a gas turbine after the release of a Safeset® coupling will result in the acceleration of the turbine because of its relatively low inertia. To keep the over speed within an acceptable limit a slipping turbo coupling can be used to between the gas turbine and the generator which has a relatively high inertia (pic. 4).

For this application the turbo coupling must meet the following design criteria.

- Rapid torque build up with increasing slip
- High availability

9. Brake properties at high speed and acceleration

Picture 5 shows the torque transmission of a turbo coupling versus a slip for generator speeds of 3000 and 3600 rpm.

The development of the Turbo coupling was concentrated on a circuit design, which has a good torque transmission capability at very high acceleration. Tests on the circuit design were carried out up to a slip of 16 % and a maximum acceleration of 6000 rpm.

10. The new design concept

Requirements

- Design with Safeset® incorporating a turbo coupling
- Quick resetting of the system after release
- Self contained unit, easily removal from the drive system

Picture 6 shows a compact design for the Safeset with incorporated turbo coupling.

The flanged-sleeve 1 on the input side is connected via the intermediate sleeve 3 to the flanged shaft 2 on the output side. The serration connects the sleeve 3 to the output shaft. A friction joint is connecting the input shaft to the sleeve 3.

The friction forces are generated by pressuring the hollow sleeve 4. The slipping torque can be set by varying the oil pressure in the hollow sleeve.

After reaching the maximum transmittable torque the input side will rotate relatively to the output side. The relative movement (slip) is used to cut open the head of valve 6 (shear tube). The oil pressure in the hollow sleeve is released and the torque transmission is interrupted. The pump-wheel 7 of the turbo coupling is connected to the flanged sleeve (input) and the turbine wheel 8 is connected to the flanged shaft (output). The acceleration of the gas turbine results in a speed difference between the coupling wheels which generates a torque as shown in picture 5. The torque is almost proportional to the slip.
The whole Safeset®-Turbo Coupling unit is designed in such a way that it can be mounted between two membrane couplings. This allows the assembly and removal of the unit without disturbing the gearbox or the gas turbine.

11. Simulations of LM 6000 fault events

Picture 8 shows the speed response of a LM6000 gas turbine and generator using the torque speed characteristic (pic. 5) of a turbo coupling size 682.

Also shown as comparison is the speed response without a turbo coupling. The significantly lower speed using a Safeset® and turbo coupling can clearly be seen. The calculation assumes the following data is known.

- Inertia of input side
- Inertia of output side
- Disconnection time of the generator
- Losses in the generator (drag torque)
- Torque/speed/time behaviour of the gas turbine considering the acceleration.

Other gas turbine responses can be calculated if above data is known.