

SFC

Start-up inverter of gas turbo-sets

Integrated compact units



Inverter as a means for start-up of gas turbo-sets

The demand of public utility companies for dependable and readily available sources of energy for peak-load coverage is reflected by the use of gas turbine groups and pump-storage power stations. Moreover, increasing numbers of gas turbine power stations use gas and steam combination processes as a means to boost efficiency. As gas turbines cannot start without external means, a start-up device is necessary driving the main generator via a static frequency converter while the main generator is working as a motor.

The approach of starting via static frequency converters is increasingly gaining ground because it offers a number of important advantages:

High degree of availability

Very good black start capability because the inverter power can be continuously adapted to the black start diesel generator, and because the power can be slowly increased from zero with practically any rate of rise, whereas other systems (e. g. electric motors) mean an immediate application of power.

Almost maintenance-free operation (no parts subject to wear and tear)

Space-saving design

Free selection of the place of installation.

This approach is particularly favourable and economical if several gas-turbo groups exist which then require only a single start-up device. Despite the high degree of availability, however, a minimum number of inverters should always be available for reasons of redundancy and start-up

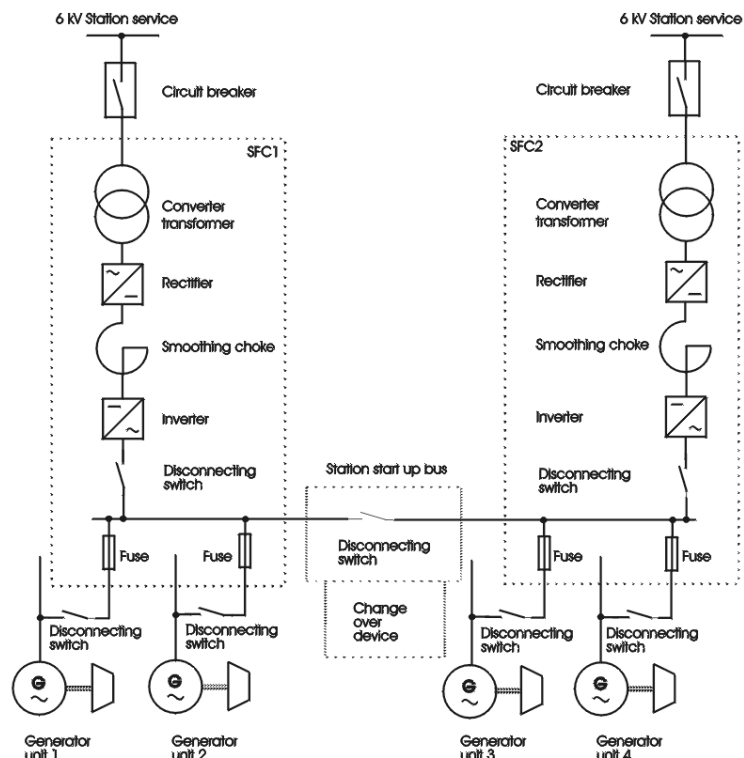
times (an inverter can start up only one gas-turbo Set at the same time). One inverter for two gas turbines with switch-over facilities to another inverter has turned out to be the optimal solution (see Fig. 1).

For many years, static frequency converters developed and supplied by AEG have met these requirements in many gas turbine power stations with a high degree of reliability. The rapid progress in the field of components (C-MOS techniques, microprocessors, etc.) has led to a considerable reduction in volume and costs of the necessary equipment and

permitted the elimination of the rotor position transducer which was formerly attached to the generator-developments which have further increased the availability of these static frequency converters and thus of the gas-turbine units. Rotor position transducers in a strongly simplified form (via three proximity initiators) are today only necessary if the following operation requirements must be fulfilled:

High torque with the turbo-set idling (e. g. for plant without oil-lift bearings) or

if turning Operation is required for the static frequency converter



1



1 Start-up of 4 gas turbines via 2 static frequency converters with change-over facility

2 Gas turbine manufacture

Cover photo: Jurong gas turbine power plant, Singapore, generator units 1 and 2, erected by Siemens/KWU using AEG compact units.

Generator power:
base load 105.3 MW,
peak load 116.0 MW

2

The speed controlled Synchronous machine

The principles of Operation of a static frequency converter can be explained via the working principles of a converter-fed synchronous machine. Fig. 3 shows the power part. The inverter normally consists of two three-phase bridge circuits whose AC voltage inputs and outputs are connected to the mains and to the synchronous machine to be fed. Their DC connections are interconnected via a DC link circuit.

In this illustration, the thyristors are identified in the order of their firing by numbers on the mains side and by letters on the machine side.

After firing of the thyristors 1 and 2 in the mains converter and the thyristors a and b in the machine converter, a current flows from the mains phase U via 1, the link circuit reactor, via a, through the motor phases U_1 and W_1 via b and 2 back into the mains phase W.

A magnetic field Φ_1 is thus generated in the motor. If an excitation current flows at the same time, a magnetic field Φ_F generated in the rotor, too. The position of the field is determined by the actual position of the axis of the excitation winding of the rotor. The two fields generate a torque whose amount is described by the following relationship:

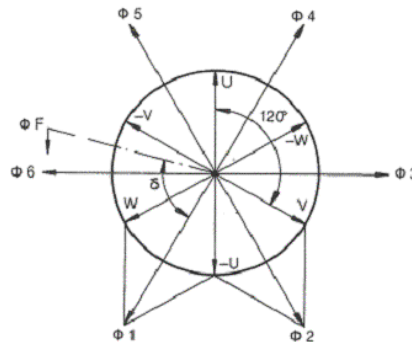
$$M \sim \Phi_1 \times \Phi_F = \Phi_1 \cdot \Phi_F \cdot \sin \delta$$

δ : angle between Φ_1 and Φ_F

The rotor starts turning and would stop at $\Phi_1 = \Phi_F$. In order to avoid this, the thyristors

of the machine converter are switched over when the rotor field reaches a certain position which means that the thyristor f fires and the thyristor b blocks. As a consequence, a current now flows through the motor phases U_1 and V_1 . The resulting stator field is shifted to the position of the vector Φ_2 (see vector diagram). A torque

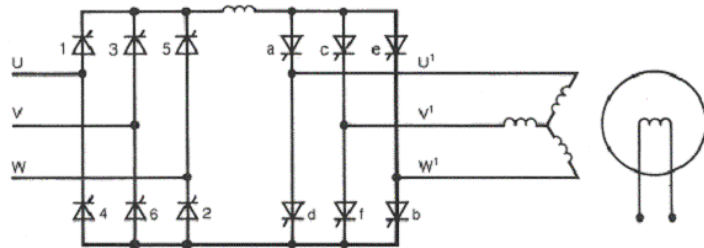
is again produced ($M \sim \Phi_2 \times \Phi_F$), and the rotor continues turning. The rotation motion of the rotor is maintained through successively switching over the thyristors. The switching sequence is determined either upon the basis of the measured machine voltage, or by means of a transducer which is firmly attached to the rotor



Vector diagram of stator and rotor field

Position of the stator field	Fired thyristors
Φ_1	a-b
Φ_2	f-a
Φ_3	e-f
Φ_4	d-e
Φ_5	c-d
Φ_6	b-c

Speed controlled synchronous machine



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3 Vector diagram of stator and rotor field of the speed controlled synchronous machine

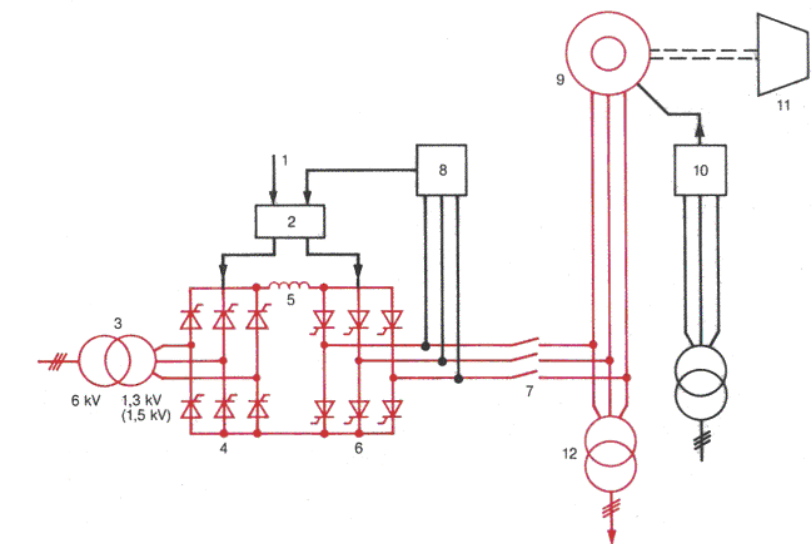
Static frequency converter, principles

The basic circuit diagram (Fig. 4) shows a gas turbine with static frequency converter. During inverter-controlled frequency start-up, the static frequency converter acts on the synchronous generator which is used as drive motor. The mains converter (4) which works as a rectifier with phase angle control supplies a DC voltage and passes on to the DC link circuit the active power drawn from the mains. The machine converter (6) works as an inverter and generates a negative voltage from the terminal voltage of the generator. It withdraws power from the DC link circuit and passes this power on to the machine. The machine voltage rises at a linear rate with the speed until the rated voltage of the inverter (usually 1.3 - 1.5 kV) is reached.

At higher speeds, the voltage is adjusted at a constant value via the generator excitation. The choke in the DC link circuit has the function of decoupling the mains and machine converters; it takes up their voltage differences and thus has a DC smoothing effect. The firing times for the machine converter thyristors are determined by evaluating the machine voltage, and - if special requirements have to be met (surmounting a high breakaway torque, or turning operation) - by means of a simple detector circuit. The generator terminal voltages are measured and signals for pulse generation formed as a function of the zero crossings. The detector signals

required for heavy starting are evaluated only in the lower speed range (≤ 80 rpm), or over the entire range of turning Operation with inverter where reduced excitation current levels are being used. As soon as a sufficiently high machine voltage is available, normal signal detection procedures via voltage measurements are applied. The current in the machine converter is commutated by the terminal voltage of the synchronous machine. At zero speed or at very low speed, when the synchronous machine is still unable to supply a sufficiently high terminal voltage, commutation of the machine converter is

achieved by intervention in the control of the mains converter. The mains converter is temporarily controlled to work as an inverter, the current in the DC link circuit and thus in the thyristors of the machine converter becomes zero. Following a rest period of approx. 2 ms, the mains converter is again forced to rectifier Operation and the next thyristors of the machine converter are fired. This process which takes place six times per machine frequency period is repeated until the terminal voltage of the machine is high enough to ensure commutation (up to approx. 6 % of rated speed).

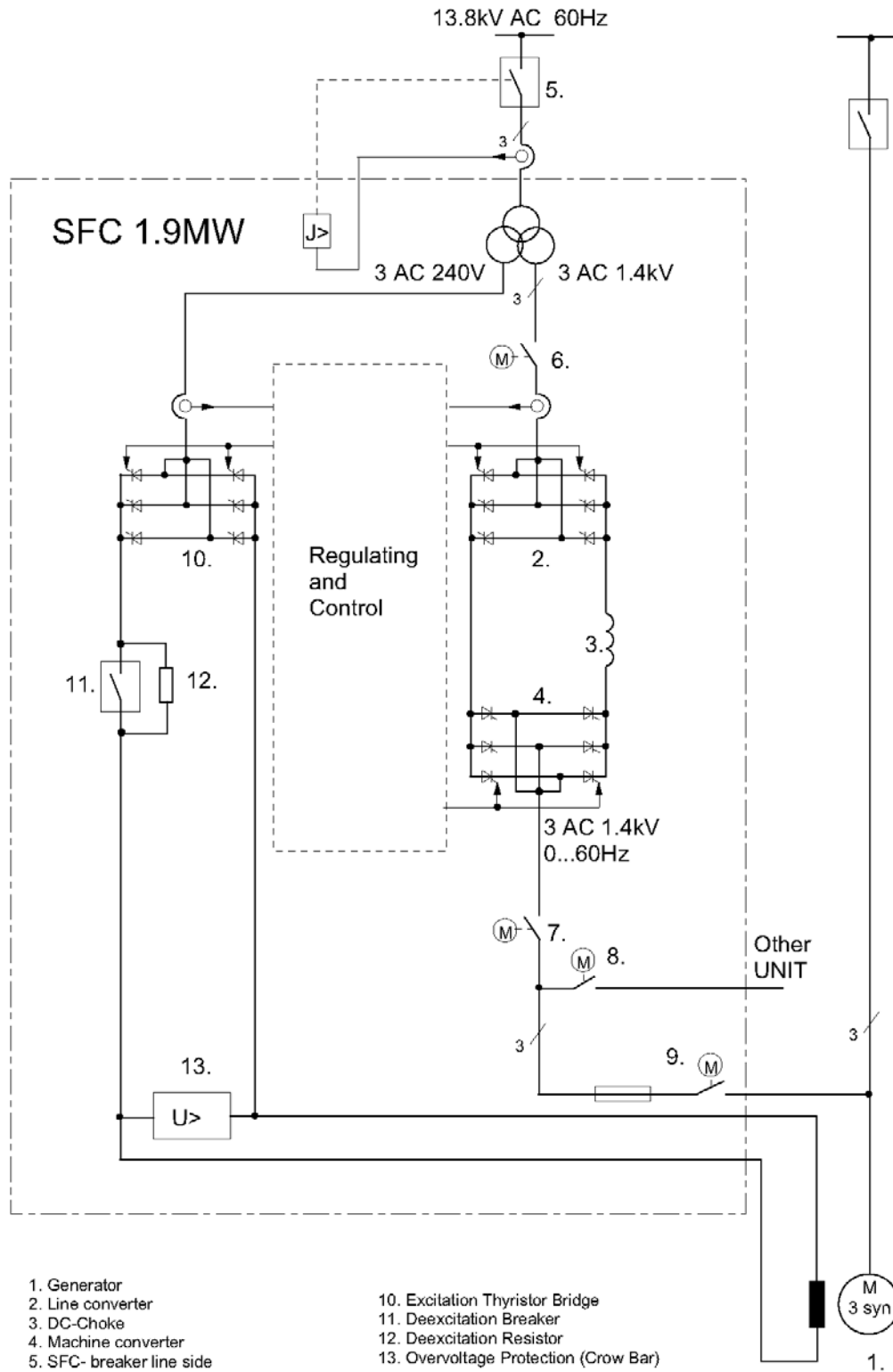


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4 Principle diagram gas turbine with static frequency converter

- 1 Control, signals
- 2 Control regulation
- 3 Supply transformer
- 4 Mains converter
- 5 Link choke
- 6 Machine converter
- 7 Isolator
- 8 Voltage detection
- 9 Synchronous machine
- 10 Excitation
- 11 Gas turbine
- 12 Block transformer

Static frequency converter plus excitation, detailed



Power rating

The power of the static frequency converter is primarily determined by the required run-up time of the turbo-set from standstill until synchronization at 3000 (or 3600, resp.) min^{-1} . In the case of gas turbine installations, this time is in the order of a few minutes. As the inverter must only be connected until a speed of approx. 2100 min^{-1} is reached, the active time until this speed is reached is somewhat shorter.

The power rating is determined in two steps. The first step is the calculation of the kinetic energy of the masses of generator, turbine, and clutch rotating at a speed of 2100 min^{-1} , and its division by the run-up time. The result is the mean power demand which is constant in time, without consideration of the counter-torque curve. As a second calculating step, this power value is adjusted by the influence of the counter-torque. The minimum power of the inverter is determined by the maximum counter torque.

The run-up process is divided into phases so that it is not necessary to choose a power value for the required inverter which would exceed the required mean run-up power by too large an amount.

Between standstill and a defined

base speed (0.1 - 0.2 rated speed) acceleration takes place at constant torque because the terminal voltage of the machine rises in proportions to the speed (constant excitation) until the rated voltage of the inverter is reached. The current is adjusted at a constant value via the mains converter.

Between base speed and 2100 min^{-1} , acceleration takes place with constant power. In this area, the machine voltage is kept constant by means of the excitation unit (field weakening operation).

Another aspect important for the power rating is the required torque. Between base speed and 2100 min^{-1} , the torque is calculated as follows:

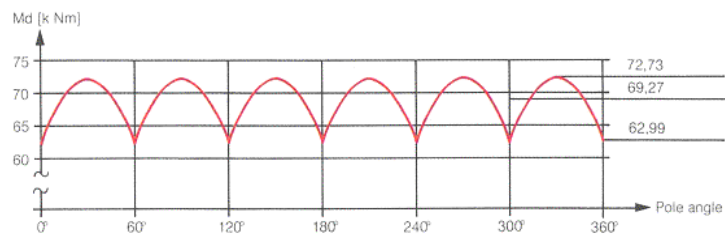
$$M_d \text{ [kNm]} = 9.554 (P \text{ [kW]} / n \text{ [rpm]})$$

The maximum torque depends upon the base speed which is in the order of 400 rpm. Example of the calculation for a 2.9-MW inverter:

$$M_d = 9.554 (2900/400) = 69.266 \text{ kNm}$$

This is the mean torque which also applies to the lower speed range under rated current conditions. Plotting the instantaneous value of the torque upon the pole position gives the torque curve in Fig. 5.

Given an optimal firing time setting, the above-mentioned example thus means a minimum of 62.99 kNm. This also applies to starting from standstill as breakaway torque, although in such a case certain allowances may be necessary in order to consider the current flowing into the transformers which may be permanently connected to the machine terminals



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6

6 Leopoldau peak power plant, Vienna, Austria
Erected by Siemens / KWU using AEG Static frequency converters Generator power: base load 85.0 MW peak load 93.5 MW

Turbine: V92 with Combust chamber

Control and regulation

The block diagram shown below illustrates the configuration of the control loops of the static frequency converter. The control system comprises the mains converter control (1), the start-up control (2), the machine converter control (3), as well as the voltage monitoring unit (4), the gate voltage controller (5), and the current actual-value monitoring unit (6).

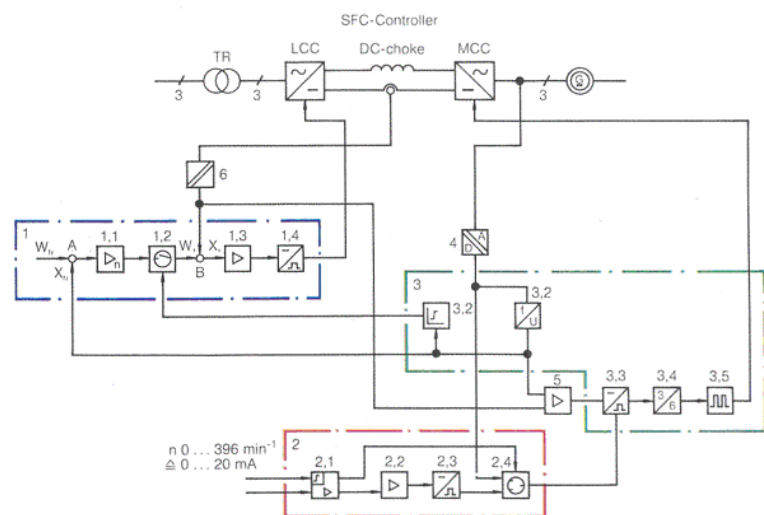
The mains converter control assembly (1) contains a speed controller (1.1) with subordinated current control (1.3). The speed controller receives a fixed reference variable w_n which is compared with the controlled variable x_n at the summation point A. The speed quantity is obtained in that the frequency of the digital signal from the voltage monitoring unit (4) to the f/V converter (3.2) is converted into an analog value. The output of the speed controller is the reference variable for the current controller. Unlike normal variable-speed drives which mostly work under part-load conditions, the static frequency converter works under full-load conditions practically all the time in order to ensure that the desired speed is reached within the shortest time possible. This means: The speed controller is overdriven, and the drive operates at its current limit. The amount of the current reference variable is fixed via a suitable rating unit which acts upon the limitation of the speed controller. Different current reference variables can be assigned to different modes of operation. The current controlled variable is measured in the DC link circuit and via the potential isolation unit (6) and compared with the reference variable at the summation point B. The speed controller does not become active until the desired speed values are reached, and until the inverter has

to work continuously (e. g. turning Operation). For start-up purposes, the commutation of the current in the lower speed range must be ensured by forcing the current to zero (clocking) because the machine voltage is still too low at that point. In the clocking mode, the electronic switching gate (1.2) interrupts the speed controller at the output so that the mains converter can be changed over to inverter operation.

As a consequence, the current in the inverter and thus in the motor phases becomes zero: The thyristors in the machine converter are reversed for commutation purposes, and the current controller can be connected to the control loop again. The output of the current controller is connected to the pulse generating unit (1.4). The firing pulses are passed on to the firing transformers of the corresponding thyristors of the mains converter.

Firing of the thyristors of the machine converter takes place depending upon the rotor position and/or the machine voltage (4). The signals α , β , γ and δ are generated

on this basis. The three coarse-track signals α , β , and γ which are offset by 120° and 180° long give information concerning the m.m.f. situation in the machine. The fine-track signals $6 \times f_m$ thus obtained is converted into an analog quantity used for speed control. In the lower speed range (clocking range), the signals can be directly used for firing pulse generation. In the higher speed range, the current in the machine converter is commutated by the terminal voltage of the synchronous machine. For this purpose, the machine current must lead the voltage; the machine works in the leading mode. In order to ensure perfect operation of the converter, the angle α between current and voltage must be at least so large that a sufficient recovery time is obtained for the thyristors at any speed and/or frequency. On the other hand, it is always attempted to avoid excessive phase displacement values in order to minimize torque losses as a consequence of an unfavourable power factor. The function of the machine converter control (3) is to find an optimal compromise between these two requirements.



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7 Control and regulation principles

1. LCC-controller
 - 1.1 Speed controller
 - 1.2 Electronic gate
 - 1.3 Current controller
 - 1.4 Pulse formation
2. Start up controller
 - 2.1 Start up interlocking
 - 2.2 Internal frequency controller
 - 2.3 Internal pulse generator

2.4 External-internal pulse selection

3. MCC-controller
 - 3.1 Trigger stage
 - 3.2 Frequency-voltage converter
 - 3.3 Pulse shifting
 - 3.4 Formation of ignition ranges
 - 3.5 Pulse formation
4. Voltage detection
5. Firing angle control
6. Actual value current controller

In order to achieve a favourable power factor of the machine, it must be attempted to minimize α . If the machine works with a constant value of α over its entire speed range, a favourable power factor is achieved at maximum speed; at low speed, however, this value is reduced because the hold-off intervals become unnecessarily long as a consequence of longer periods so that the utilization factor of the inverter becomes less favourable.

The speed-dependent angle α could be optimized as follows:

Depending upon machine speed and stator current, the displacement angle α which is optimized by means of the angle presetting unit (5) is shifted. In this way, the maximum possible torque is achieved over the entire speed range because the inverter always works with the optimal extinction angle.

The exchange of signals with the entire power plant control proceeds via a programmable logic control system. This system permits a signal link to be established with master computers (currently AEG CP 80-A500, A500F) via a signal bus.

The requirement of successively starting several gas turbines via one static frequency converter was considered a specially important element of the control System



8

8 Hinged frame with plug-in cards for static frequency converter and excitation control. Two automatic control channels.

System components

The Compact unit

Semipol® excitation + static frequency converter = Compact unit

Miniaturization of electronic components has made it possible to combine the two central elements for operation and start-up of gas turbine installation in one assembly. Modern thyristor technology plays an important role in this field. It is, for example, not necessary to use thyristors connected in parallel for the power range from 1000 kW to 5000 kW. The development of components and modules for control purposes has been equally favourable: Space requirements could be reduced to a level which permits both control system for Semipol® + SFC (static frequency converter) to be installed in one hinged frame. Further advantages are obvious:

Systems belonging together come from one source, thus:

no "plant cabling" work on site

system checks at the manufacturer's works

less commissioning work and costs.

Static frequency converter installation with start-up control

Another principle which is also

offered by AEG is a static frequency converter installation with auxiliary excitation only for static frequency converter operation plus – possibly - testing purposes. This type of installation is somewhat more complex because it requires two excitation units for gas turbine operation. Under particular circumstances, however, this plant concept may offer financial advantages.

In general, static frequency converters can be divided into two function blocks: The power circuit assemblies and the information electronics.

The power circuit consists of converter transformer, mains converter, link choke, and machine converter. The information electronics block comprises the control and regulation components.

The signal processing part consists of plug-in type universal modules from the Geatronic® system family. The plug-in cards from the Logidyn program are used for control and monitoring functions. The plug-in cards of the Modicon system are used for digital signal processing. In the form of isolating and memory modules, they isolate peripheral

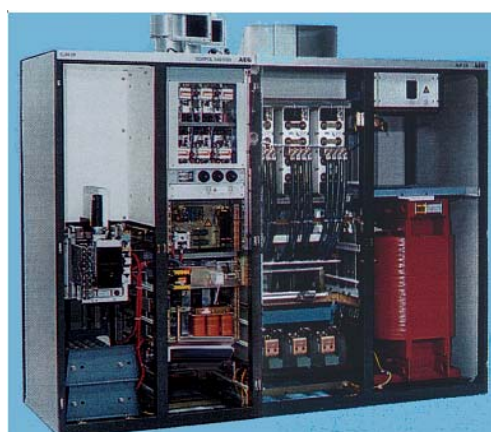
control signals and pass on commands to the primary process. Both systems permit direct function checks by means of measuring sockets on the front panels.

The complete control system for the static frequency converter is installed in a hinged frame (including Semipol® control) which can be turned through 150°. The components necessary for the voltage supply of the information electronics, as well as relays and circuit breakers are mounted on a second installation level. The installation shown is designed for the power range from 2 MW to 2.9 MW.

The left part of the compact unit (Fig.10) contains the DC link circuit choke and the damping devices belonging to the thyristor bridges. The thyristors are air-cooled. The compact unit is enclosed at its top and sides and accessible through doors on the front and rear. The rating of the converter transformer (oil transformer for outdoor installation or cast resin transformer for indoor uses) is determined upon the basis of the start-up power



9 2.9-MW compact unit.



10 Rear view of 2.9-MW compact unit.

Power SEC	Apparent power of mains or transformer. resp.	Rated power of inverter	Dimensions of compact unit
1.0MW	1280 kVA	1300V	2400 x 1000 x 2500 mm
1.4MW	1810 kVA	1300V	2400 x 1000 x 2500 mm
1.9 MW	2440 kVA	1300V	2400 x 1000 x 2500 mm
2.9 MW	3720 kVA	1300V	3000 x 1000 x 2500 mm
5.0 MW	6370 kVA	1500V	3300 x 1000 x 2500 mm

Plant adaptation

Modes of operation

AEG has developed a standard concept for static frequency converters in which great store was set by the smooth interplay with the general control of the power station. In this context, the possibility of successively starting several gas-turbo sets via one static frequency converter has already been taken into account. The desired modes of operation of the gas-turbo sets are adjusted by the automatic control system of the power station or at its control stand where the start command is also given. These signals, which are received from the primary automatic control system, are processed in the control part of the static frequency converter in such a manner that the commands for the different gas-turbo sets are mutually interlocked so that simultaneous starting of several turbines is not possible. The gas turbines must run up successively.

A new mode of Operation can only be selected if the static frequency converter is powerless. The individual control commands in potential-free form are first checked for permissibility by a monitoring unit, which also receives all other status messages of the converter and of the plant. Only then will the inverter be connected and the flow of power released by the control system. All important operating values are continually checked for staying within the permissible operating limits. If any deviations are detected, the flow of power is cut off and the inverter switched off and disconnected from the generator. The modes of operation

which can be executed by a static frequency converter fulfil the following functions:

Power Operation and/or mains start

The static frequency converter works with the maximum power and accelerates the gas turbine. When a speed of 2100 min⁻¹ is reached, the inverter is automatically disconnected and thus available for further starts - if necessary, for the second gas-turbo set. The gas turbine automatically accelerates to rated speed (3000 rpm or 3600 rpm, resp.).

Black start

The static frequency converter works with the minimum power which is necessary to accelerate the gas turbine over its maximum counter-torque. When a speed of 2100 rpm is reached, the inverter is switched off again. The inverter is not fed from the normal mains but via a standby diesel generator.

Phase shifter start

The generator, which is disconnected from the gas turbine, is accelerated to 3150 rpm or 3780 rpm, resp., with full inverter power and switched off when this speed is reached. During the coasting phase, the generator is synchronized with the mains at a speed of 3000 rpm or 3600 rpm, resp.

Braking after phase shifter operation

Only the excitation unit is switched on for braking. Depending upon the required braking time, deceleration

takes place either through the losses of the generator only with no-load excitation current, or via an additional braking resistor. The excitation unit is switched off when a speed of 200 rpm is reached, and as the coasting process proceeds, the generator is again connected to the turning turbine.

Operation as shaft turning unit

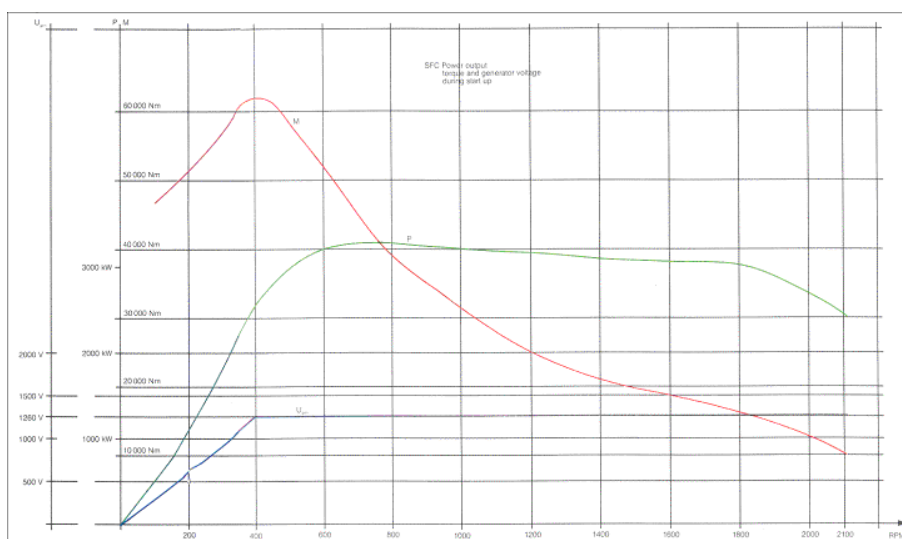
The desired speed is adjusted at the speed controller of the inverter and the turbine turned at low speed (approx. 100 min⁻¹) by means of the static frequency converter after power operation. This mode of Operation requires three proximity initiators as rotor position transducers.

Washing Operation

In order to clean the turbine with water or other media, the machine set is accelerated to approx. 600 min⁻¹ by means of the static frequency converter. This speed of the turbo-set is maintained until a switch-off command is given.

Proven for years

More than 80 static frequency converter installations have been in operation since 1973. From the very beginning, a crucial design aspect was a very high degree of reliability. We have consistently applied our know-how to our customers' benefit so that we can supply installations whose efficiency, low maintenance requirements, and availability have been demonstrated by large numbers of practical applications



11 Run-up diagram of a 100-MVA gas turbine



**AEG Berlin
factory for current rectifier products**

AEG have been developing, projecting, manufacturing and selling power electronics plants and components for more than 60 years. The new production facility in Berlin with more than 46000 square metres of production and office premises, around 1000 employees and modern production equipment has been in service since 1984 to provide the facilities required to consolidate and expand upon the technological lead held by the company. During the last 8 years AEG's propriety factory together with its highly experienced engineers and personell was rented and operated by several different companies. Today it is Converteam GmbH a daughter of Barclays Bank

Characteristics of the systems, plant and components include innovative technology, high safety and reliability levels and quality assurance with extremely accurate quality control and operational testing facilities. The extensive service provided meets the high quality standards of the products.

The reference list of different power electronics applications are long and not limited.

Products and Services

The division program includes:

- Converter for drive technology
- Motion control systems
- Converter for power plant technology
- Rectifier for high voltage and high current applications.
- Construction of controls and workshop Services
- Wind generation applications
- Converters: 50/60/16 2/3 Hz

These products are being marketed by the specialized departments for plant construction as part of the total plants

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We take care of your Power Quality