

Dynamic reactive power compensation

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Application for an arc furnace



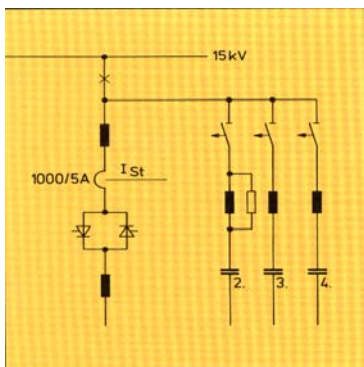
Arc furnaces producing steel have due to the stray inductance of the furnace transformers and the high line inductances a considerable reactive power demand. Installing a dynamic reactive power compensation system enables the voltage values in the supply network to be stabilised, unsymmetrical loads to be balanced and, with the help of filter circuits, voltage distortions to be minimised.

Early in 1986 AEG -Iberica received the order to modernise the MEGASA electro steelworks in Spain. Following approximately one year of construction, the new steelworks commenced operation in 1987. Within the framework of this order, AEG's Power Electronics and System Construction Group in Berlin supplied an installation which provides dynamic compensation of reactive power and reduces system feedback caused by the arc furnace in the steelworks.

Steel production using an arc furnace

The proportion of steel produced in electric arc furnaces is increasing continuously throughout the world. Since steel production has almost stagnated during the last ten years, a growth rate in electro-steel is all the more significant. It results from the increasing appeal of the arc furnace flexible and varied possibilities of use, improved technologies, falling operating costs etc.

In regions which are not accessible through close-meshed and high-power networks, the electrical power supply for large and efficient arc furnaces often poses considerable problems. The reasons for this are the high power requirements and the effects on the supply system which feed them. Modern power electronics installations for dynamic compensation of reactive power reduce the unwanted side effects and allow additionally - as a result of increased power conversion in the furnace - a reduction in the melting times. In this way they reduce the investment and operating costs.



Overall structure of the dynamic reactive power compensation system

Operating characteristics of an arc furnace

The connection load for arc furnaces is as a rule up to 100 MVA; this limit is often noticeably exceeded. Because of their high power requirement, arc furnaces are usually connected to a separate in-works intermediate voltage system (10 kV to 30 kV), which is fed from a superordinated high voltage network. The construction and operation of three phase arc furnaces are quite simple: the heat required to melt the charge is produced by arcs, burning between three graphite electrodes and the charge. The graphite electrodes are connected to special transformers, which are used for adjusting the electrode voltage of several hundred volts; the electrode currents are in the

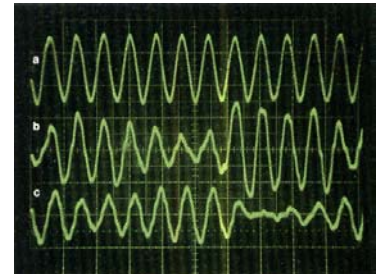
kiloamp region. The power converted to heat in the arc is matched to the progress of the melting process by selection of the secondary voltage and the distance between the electrodes and the charge (arc length). The flow of current over the arc and the voltage drop across it are subject to many influences (arc length, ionisation level, inter-acting electromagnetic forces, etc.), which cannot be fixed in advance. The processes run differently in the three phases, so that all states between electrode short-circuit and arc interruption can occur. As a result of this, currents flow in the supply system connections to the furnace transformer, the value of which can change quite randomly within a wide range (zero to three times rated current) within milliseconds. This also applies to the differences between the three phase currents; hence the lack of loading symmetry in the three phase system. In addition, the current has harmonic components. A further problem is the phase shift between mains voltage and current, which is caused by the stray inductance of the furnace transformer and the substantial line inductances. The result is a considerable inductive reactive component in the current. However, only the resistive component of the power in the arc can be converted to heat. The physically unavoidable reactive current is, on the other hand, an additional load on the supply. It must thus be taken into account in dimensioning network plant (generators, transformers, lines, etc.) and it increases the investment and operating costs.

Feedback to the supply network

The arc furnace has feedback effects on the supply network because of the characteristic behaviour of the current:

- the supply voltage falls as a result of the reactive power demand.
- the supply voltage fluctuates, because the reactive power demand changes rapidly and over a wide range.
- the three phase supply voltage is unsymmetrical because of the

- different current values in the three phases.
- the sinusoidal shape of the supply voltage is distorted by the presence of harmonic currents.



Current and voltage characteristics in the operation of the arc furnace and the dynamic reactive power compensation. top : voltage of the 15 kV supply. centre: current in the lines to the furnace transformer bottom: current in the lines to the thyristor controlled chokes.

Many users connected to the public supply system are adversely affected in their normal operations if system feedback exceeds a certain level. Variations in the brightness of electric lights (flicker) occur, if the voltage variations during arc furnace operation are too high. The capacity of the supply network therefore sets a limit to the connected arc furnace power. Normally there is no disturbing feedback if the short-circuit power of the network at the point of common coupling is about one hundred times the furnace power. This criterion compels either high investment in constructing the public supply network or restriction to an economically unsatisfactory power for the arc furnace.

A way out of this is offered by modern rectifier technology. Dynamic reactive power compensation systems substantially reduce the disturbing mains feedback caused by the arc furnace and the problems of operating it, even in less powerful networks, are reduced.

Reactive power compensation of arc furnaces

The main cause of arc furnace supply feedback is the unsymmetrical and fluctuating inductive power requirement. Compensating for inductive power by means of capacitors is a practice which goes back decades. This measure alone does not, however, bring the required results for every case in which the user's reactive power is subject to large and particularly rapid fluctuations. Rapid adjustment of the compensating power is required, in order to match it continuously to the user's reactive power and thus to stabilise the voltage. In modern systems for dynamic reactive power compensation therefore, a choke in series with an anti-parallel semiconductor rectifier bridge (thyristors) is connected in parallel with the capacitors, which are made into filter circuits by connecting chokes in series. By phase-chopping control of the thyristors, the inductive current of the chokes can be adjusted continuously from zero to maximum value.

The capacitors are so designed that they can cover the maximum capacitive power demand. The inductive power demand caused by the arc furnace only reaches sporadically the peak value for which the compensating capacitors are designed. If the peak value is not reached, there is overcompensation. In this case the current can be so adjusted by means of die thyristor-controlled chokes that the sum of this reactive current and the reactive current of the arc furnace corresponds to the capacitive current (of the filter circuit).

As result the incoming current will be a resistive; only resistive power is taken from the supply system.

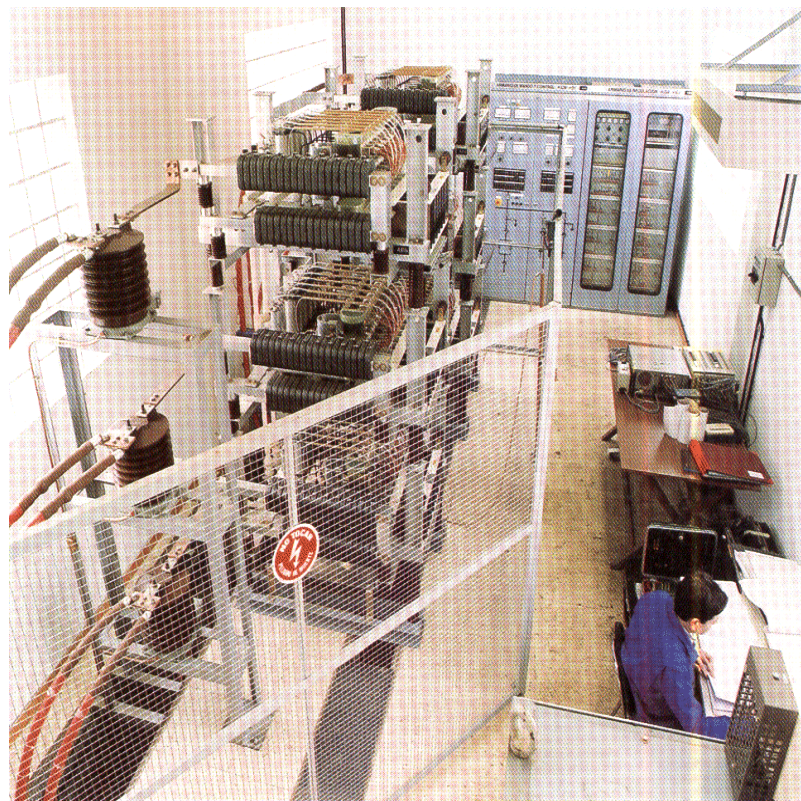
In order also to allow for unsymmetrical loading due to the arc furnace, control of the thyristor-controlled chokes must be separate in all three phases. This is possible with a suitable open and closed loop control system. In addition, with adequate rating of the complete compensating system, the voltage unsymmetrical resistive current in the lines to the arc furnace, which remains even after compensation of the reactive power, can be distributed equally over the three phases of the supply system connection.

Because events in the arc furnace are unpredictable, adjustment of the compensating power can only be

effected when the load change has already occurred. The measured values must therefore be picked up and processed rapidly in the open and closed loop control system, so that the unavoidable delay times are as short as possible. In order to deal with this high dynamic requirement, the current in the lines to the arc furnace is measured directly and brought to a short-delay electronic evaluation circuit with correct symmetry. The result is reaction times which are on average roughly half a supply system period. This core of the open and closed loop control system is supplemented by further devices which protect and monitor the installation.

- it absorbs the harmonic currents which are produced by the arc furnace and the thyristor controlled chokes and thus reduces voltage distortions.
- it prevents resonance phenomena which may be excited by the harmonics when using unchoked capacitors.

As a result not only the required compensation power but also the harmonic currents and their effect on the frequency-dependent behaviour of the supply system are involved in the design of the filter circuit system. The total capacitor power is distributed over two or four filter circuits. As tuned frequencies, those harmonics are selected (in a 50 Hz supply therefore



High voltage rectifier and control cubicles

Effects on the supply system

A dynamic reactive power compensation system working on this principle thus covers the actual arc furnace reactive power demand and has a stabilising effect on the level of the supply voltage. The filter circuit system has three tasks here:

- it provides the required constant capacitive fundamental frequency reactive power.

100 Hz, 150 Hz, 200 Hz etc.), since the largest harmonic oscillations occur at these frequencies. Additional buffer resistors give the filter circuit a broadband characteristic, so that harmonic currents from the arc furnace with intermediate frequencies can also be picked up. With suitable Filter circuit rating, it is possible with a dynamic compensation system not only to stabilise the supply voltage but also to keep voltage distortions within acceptable limits.

Adjustable compensation power is required for the tasks described, which is roughly equal to the input power of the arc furnace, but must occasionally exceed it. The state of the art in rectifier technology however allows the direct connection of such high powers to the intermediate voltage supply system without matching transformers.

The question arises here as to why, with the principle explained above for the complete compensating system, the round about route using thyristor controlled chokes is taken rather than adjusting the capacitor current directly. The continuous adjustment of capacitive currents in simultaneous strongly unsymmetrical operation requires special self-controlled rectifiers, which at present cannot compete economically with the indirect method described. On the other hand, the simpler, direct method of stepped switching of capacitors using thyristor switches, has poorer dynamic properties due to the longer dead times.

Structure of the compensating circuit

The dynamic reactive power compensation system for the Electro-Steelworks has the following important characteristics:

- Voltage of the public supply network: 132 kV/50 Hz
- Short-circuit power of the 132kV

network: 1100 MVA to 1800 MVA

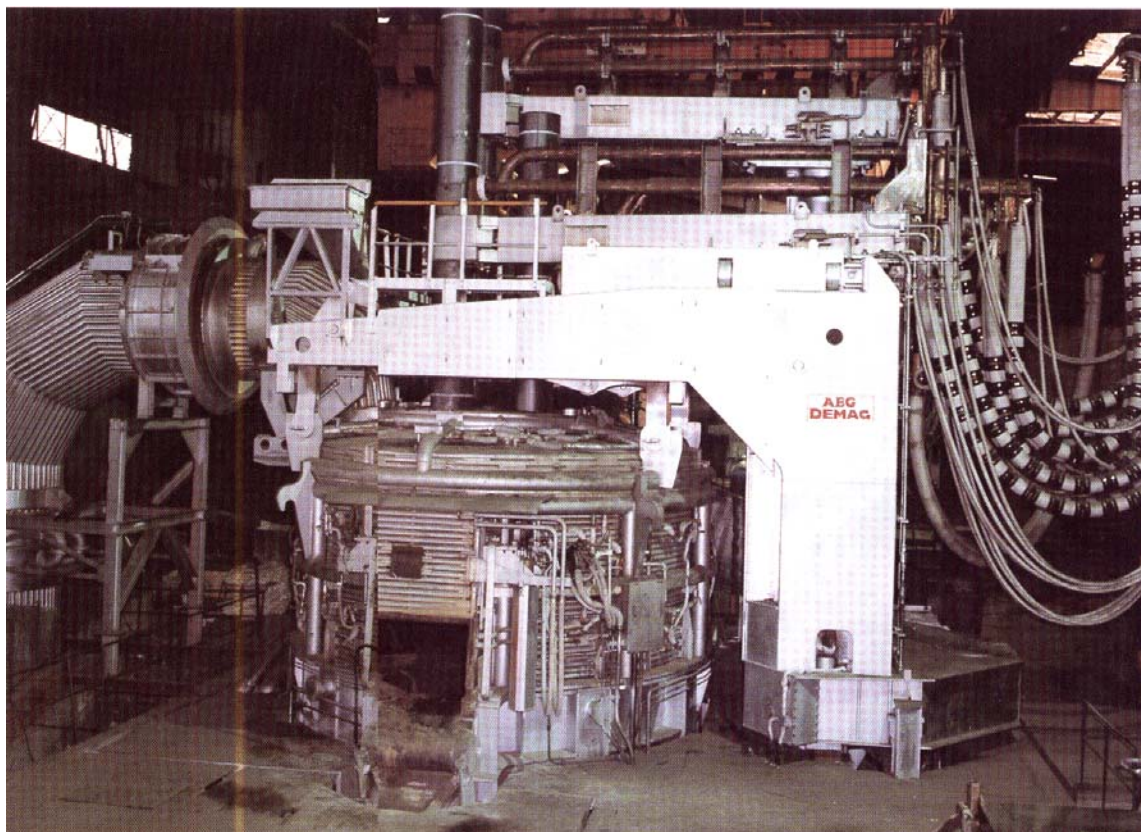
- Feed transformer power: 30/39 MVA; $\eta_k=7.6\%$
- Steelworks supply system voltage: 15kV
- Arc furnace capacity 70 t
- Furnace transformer rating 42/47 MVA
- Compensation system input voltage: 15 kV.
- Compensation system power 0 to 42 MVar, capacitive
- Installed capacitor power: 76 MVar.

With the exception of the rectifier section and the open and closed loop controls, the total compensation system is designed for installation in the open air. The chokes connected in series with the capacitors and the thyristor-controlled chokes are self cooled air-cored solenoids without iron core; their inductance is constant, independent of current. Each phase of the thyristor controlled chokes consists of two half-coils of the same inductance, mounted one above the other. The semi-conductor bridges were connected electrically in each case between the half-coils of a given phase, so that the current was limited in the event of earth leakage faults. The semi-conductor bridges, together with the open and closed loop control system are in an adjacent building. They are constructed from the AEG Megasemi rectifier system, which was developed specifically for applications

in the intermediate voltage range. Series connection of several high-blocking voltage power thyristors, in the form of disks, is required to control the 15 kV voltage. Fast data exchange is provided by the Logistat A030 automation system fitted - a compact, stored program, microprocessor-supported controller.

The heat dissipated in the semiconductor bridges is led off via distilled water coolers located between the individual thyristors. The cooling uses distilled water with a very low electrical conductivity, which is controlled and held constant by a water treatment and cooling plant belonging to the Megasemi system. Water cooling allows high packing density of the thyristors and space-saving rectifier design even at very high power. The racks for the open and closed loop control devices contain, in addition to the controls for the thyristor controlled chokes and pulse generation for thyristor triggering, all the necessary systems for operation, measurement, protection and monitoring of the complete system including the filter circuits.

In view of the high potential at which the thyristors are held, the triggering pulses to the thyristors are transmitted not by magnetic pulse converters but optoelectronically using optical cables. The installation has been in fault free operation since August 19



Electric arc furnace 42 MVA, capacity 70 tons

Effects of the dynamic compensation system on the operation of the arc furnace

In addition to the saving in electrical reactive power and the improvement in the quality of the voltage supply of the feed network, there are further advantages connected with the dynamic compensation system, which manifest themselves in the arc furnace itself. Because the network voltage is stabilised, the voltage level at the terminals of the furnace transformer coincides roughly with the rated voltage. This voltage is then available for a higher power conversion in the arc. The power conversion can rise by 25% or more; this leads to shorter melting times. This effect is the greater, the lower the power of the supply transformer is. In the system described here, its power could be restricted to the resistive power converted in the furnace, since there is no significant reactive power flow through the feed transformer. This leads to savings in investment costs. The lower noise emission according to the operating personnel - when running the furnace and the dynamic compensation system is a further positive effect. It can be explained in terms of more stable arcs and fewer electrode short-circuits and thus also fewer reignitions. This also leads to longer lifetimes for the graphite electrodes and furnace lining.

Summary

As a result of their high and strongly fluctuating power consumption, electric arc furnaces cause feedback effects in power supply networks which can have a disturbing effect on other users. The main cause of this phenomenon is the unavoidable reactive power component of the arc furnace, which demands not only increased investment costs on the supply network side, but also leads to an increase in the regular energy costs. Modern systems with rectifiers for dynamic reactive power compensation which can rapidly adapt themselves to the fluctuating reactive power demand, reduce these disturbing effects. At the same time, they contribute significantly to a reduction in arc furnaces operating costs and to improved operating behaviour. In the long history of development of arc furnaces, which began in Germany in 1905 with the first of the arc furnaces equipped by AEG, dynamic reactive power compensation is a major step, which makes the technology of steel melting using electrical power an interesting alternative to other processes for steel smelting.

Further applications

Dynamic compensation installations are also being applied in many other

areas: for reactive power compensation of controllable rectifier drives, of electrical welding plants, or in public supply networks.

The authors

Manfred Clemens, born 1943, studied electronics at the Staatliche Ingenieurakademie Gauss, Berlin. In 1968 he came to the then Rectifier Works of AEG in Berlin and was active first in development and later in sales and design of rectifier systems. At present, he is head of sales for reactive power compensation and power generation rectifier systems in the Power Electronics and System Construction Group.

Dr. Ing. Gianluigi Mapelli, born 1938, studied electrical engineering at the University of Milano. He graduated in the field of electrical machines and their automation processes. In 1969 he came to AEG at the Berlin rectifier works. He was active in the development of control systems and in the design of electronic controls for the electrical power sector. Since 1984, his fields of activity have been the supply system feedback effects of rectifiers, anti reactive power compensation using rectifiers.



**AEG Berlin
factory for current rectifier products**

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