Decemberized Control and Automation of Gas Turbine and Combined-Cycle Power Plants

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ABSTRACT

Unfired combined-cycle power plants of Siemens/KWU design each comprise five different package-engineered functional areas of mechanical and associated electrical equipment which are matched to different fuels, site conditions and operating requirements in order to achieve optimum power generation with each application. A modular programmable microprocessor-based automation station allocated to each functional area sequentially controls and protects all the equipment therein. By means of a redundant bus system all the functionally distributed automation stations are connected to one another and to a central control room where VDU screens provide operators with an in-depth insight into the running performance status of the entire combined-cycle block at all times. Function keyboards and back-up conventional hardwired controls permit operators to intervene in the automatic operation of the station whenever desired.

INTRODUCTION

The numerous advantages of generating electric power in unfired combined-cycle installations are well recognized. Foremost is the outstandingly high overall operating efficiency due to exploiting the otherwise waste heat exhausted by one or more gas turbines to raise steam for the generation of additional power in a bottoming steam turbine. Since the steam turbine output, which generally amounts to more than half the total output of the associated gas turboset(s) with a simple-cycle efficiency of roughly 33 percent, is gained without any extra fuel, the net energy conversion efficiency today usually exceeds 50 percent, i.e. over half the calorific content of the gaseous or liquid fossil fuel combusted in the gas turbines is delivered in the form of electricity to the external transmission system.
Despite achieving overall operating efficiency levels that are unattainable with any straight steam cycles, even those employing extremely expensive double-reheat supercritical-pressure boilers and turbines, unfired combined cycles utilize only highly conventional power generation equipment, namely standardized gas turbines, unfired heat-recovery boilers (convection heat exchangers) and non-reheat low-pressure steam turbines with correspondingly simple auxiliary equipment. This fact not only promotes operating reliability, but also results in considerable savings in equipment costs due to the absence of a large fired boiler and reheat turbine for high-temperature high-pressure steam conditions. As a general rule it can be stated that the capital investment required for an unfired combined-cycle block is at least 20 percent less than that for a comparable reheat steam boiler/turbine power plant unit.

The unfired combined-cycle concept is thus unique in providing the most efficient thermal power generation option at a considerably lower cost than any of the available lower-efficiency straight steam cycles. Since both the fixed (initial capital repayment) costs and the operating costs are lower because of the savings in investment and higher overall efficiency respectively, the electricity production costs are substantially less in the case of unfired combined-cycle installations than with any equally rated reheat steam boiler/turbine power plant.

**MODULAR DESIGN OF GUD POWER PLANTS**

The acronymic designation GUD from the German words “Gas und Dampf” meaning “gas and steam” is applied to those unfired combined-cycle installations which are designed and supplied by the Authors’ company (Fig. 1). The design of such plants is purposely not standardized, but instead is based on the modular principle so as to avail of the inherent flexibility of the unfired combined-cycle concept and thus be able to secure an optimum power generation solution based on the actual fuel(s), specific site conditions and operating requirements of each individual project application /1/.

The heart of any unfired combined-cycle power plant is, of course, the gas turbine itself. It is essential for combined-cycle operating availability and reliability that we use proven gas turbines of heavy-duty design, which perform equally satisfactorily as the associated dependent equipment, namely the unfired heat-recovery boilers and bottoming non-reheat steam turbine, be selected. GUD plants, for example, employ Model V84 and V94 gas turbines for 60 Hz and 50 Hz power applications respectively. The 3600 RPM Model V84 gas turbine has an ISO base-load capability of 103 MW at its generator terminals /2/. The corresponding ISO rating of the sister 3000 RPM Model V94 gas turbine is 150 MW /3/.

GUD plants are divided into five different types of functional areas:

1. Gas turbotset(s)
2. Heat-recovery boiler(s)
3. Feedwater and CW supply
4. Steam turbotset with condenser
5. Miscellaneous, e.g. fuel and water treatment, non-standard auxiliary equipment, etc.

Each of these functional areas comprising a mechanical and associated electrical equipment complex with clearly defined technological functions is designed as a package-engineered module. Only in the case of the gas turbotset functional area is the module standardized around the Model V84 or V94 machine with its also standard ancillary equipment. The sole variable features are the burners and fuel injection to match the fuel(s) and to fulfill the NOx-emissions limitations. The design of functional blocks for exhaust-gas recovery and utilization are package-engineered in accordance with the actual site performance of the gas turbines which strongly depends on the ambient temperature and elevation, as well as on whichever fuel is fired. They are also optimized in conformity with other site conditions, e.g. circulating-water (CW) temperature, as well as with the specific operating requirements of the plant. The fifth functional area is mostly custom-designed for non-standard peripheral station equipment.

Each functional area is equipped with an electric power supply system and with its own dedicated electronic controls and protection so that it can be automated independently of the other areas of the plant. In other words, the electrical switchgear and I&C equipment are distributed both functionally and physically. Functional decentralization and dedication simplify the power-supply and control schemes by limiting them to well defined separate areas and functions. Physical decentralization allows the motor control centers and electrical hardware in the specific areas of the mechanical devices they supply, control and protect, thus simplifying and shortening the cable interconnections.

This decentralized I&C concept called MICHOS standing for Multiple Information Control and Observation System was specially developed for gas turbine and GUD plants. It permits the ability to build combined-cycle plants in stages, first the gas turbines, either simultaneously or sequentially, and later the heat-recovery boilers and common bottoming steam turbine cycle. Such “progressive generation” allows gas turbines to be erected with short lead times and operated initially in simple cycle. The revenue from them can be used to finance the later installation of the boilers and steam turbotset to generate over 50 percent additional electric power without any extra fuel consumption. By building combined-cycle plants on such a flexible phased-construction basis, the station capability can be increased step by step in close conformity with actual load demand growth. This prevents excessive capital outlay caused by overexpansion due to the load not growing in accordance with long-term forecasts /1/. It also alleviates the cash flow burden in completing combined-cycle blocks.

The combined-cycle process (Rankine cycle superimposed on a Brayton cycle) of converting the chemical energy in fossil fuel to electric energy can be broken down into numerous largely autonomous technological functions. These functions are organized for the purpose of controlling GUD block operation by a hierarchy of sequentially controlled functional groups and subgroups. A functional group is a complete functional entity from the point of view of plant automation, e.g. “feedwater circulation” is a functional group within the functional area covering the feedwater and CW supply systems for the heat-recovery boilers and steam condenser. Each feedwater pump together with its auxiliary drives, valves, controls and instrumentation represents a functional subgroup or loop. Such high-level automation functions are implemented in separate functionally distributed microprocessor-based automation stations. The subordinated subloop controls form the lower level of the automation functions which are implemented in extension units (plug-in cards) belonging...
to the process interface section of each automation station. These low-level functions comprise the open-loop (on/off) control or the closed-loop (modulating) control of all the individual motors, motor-actuated valves and solenoids, as well as the acquisition of all the binary and analog measured data and contact-status information required for safe automatic sequential control. All the logic associated with plant protection is programmed in binary calculation cards which are also included in the process interface. Since sufficient control elements, indicators and recorders are hard-wired directly to these process input/output-signal cards, safe remote manual operation of the plant is assured even in the event of the failure of an automation station or of a redundant bus data link.

Each gas turboset functional area is equipped with its own fully self-sufficient local control panel to allow it to be automatically or manually run in the simple-cycle mode. A centralized control room is thus only necessary to coordinate all the functional areas of a completed GUD block and to provide optional supplementary operating and monitoring functions to the normal MICOS scope. The following describes the control and automation concept of a GUD 2.94 or 2.94 block which facilitates it being built in two phases. Initially two Model V84 or V94 gas turbines and subsequently a pair of heat-recovery boilers and a common bottoming steam turboset.

SIMPLE-CYCLE GAS TURBINE POWER PLANT

Gas Turboset Power Control Center

Each Model V84 or V94 gas turbine is provided with a so-called power control center (PCC) which comprises all the intermediate and low-voltage electrical apparatus required to operate it together with its auxiliaries, as well as the MICOS electronic equipment for all the associated control, automation and protection functions. A complete PCC for each gas turboset functional area is accommodated within three standard prefabricated containers, each almost 12 m long, approx. 3.5 m wide and 3.57 m high.

The advantage of mounting the PCC equipment in such containers is that it is installed and connected in the factory where it is also functionally tested in every respect. The preassembled and precommissioned PCC containers are shipped separately to the construction site and can be mounted on simple strip foundations. The preassembled and precommissioned PCC containers to be delivered rapidly on request. The relevant documentation including all the connection diagrams can also be supplied at short notice.

The single-line diagram (Fig. 2) of the gas turboset functional area depicts the basic interconnection of the intermediate-voltage (4.16 kV, 60 Hz or 6 kV, 50 Hz) switchgear, the special gas turbine start-up equipment, the low-voltage (480 V, 60 Hz or 400 V, 50 Hz) switchgear, as well as the 220 V and ±24 V d.c. supply systems. A generator breaker is only necessary if no adequate alternative off-site intermediate-voltage power source is available for start-up purposes. The floor plan (Fig. 3) of the standard triple-container PCC for the gas turboset functional area shows where all this equipment is located.

The first container (UBA 01) houses two maintenance-free fire-resistant dry-type transformers (one for the generator excitation system and the other to supply the low-voltage busbar from the intermediate-voltage bus-
bar) at one end. The remaining space is occupied by a double row of a.c. and d.c. switchgear cubicles, complete with battery chargers and automatic synchronizing equipment, as well as by a row of electronic control and protection hardware cabinets. The low-voltage feeders are not protected by fuses which have to be replaced, but instead by compact circuit breakers. The side partition walls of the first and second bolted together containers are removable so as to allow personnel to move freely inside them (Fig. 4).

The second container (UBA 02) accommodates mainly the equipment required to start up the gas turboset. Any Siemens/KWU gas turbine is started up by motoring its generator, thereby accelerating it by variable frequency from standstill or from approx. 100 RPM (the speed at which the rotor is turned by means of a shaft-mounted oil-hydraulic turbine drive) within two minutes to approx. 70-percent rated speed when the turbine is fired and the rotor further accelerated up to full speed for synchronizing and initial loading. The transformer supplying the start-up power is housed at one end of the container close to the variable-frequency converter which is enclosed in cubicles along with the generator solid-state excitation equipment to form a compact combined assembly. The a.c. output from the variable-frequency converter is fed during start-up to the generator stator windings via three motor-driven disconnecting switches which are mounted on top of the generator P.T. cubicles. Consequently, the PCC must be located directly below the generator terminal busbar extensions so that the single-pole switches can be connected with the isolated-phase ducts. Cabinets fitted with maintenance-free hermetically sealed 220 V and +24 V lead-acid batteries are situated at the other end of the container.

The totally enclosed intermediate-voltage switchgear is installed in the third container (UBA 03). This switchgear features vacuum circuit breakers which are mounted in withdrawable units for easy maintenance. There is usually enough space in this container either to consolidate the intermediate-voltage switchgear cubicles for two gas turbosets or to accommodate also a low-voltage power distribution system for any special non-standard gas turboset ancillary equipment, as shown in Fig. 3.

If the gas turbine power plant should have black start-up capability, an emergency diesel engine with a generator to feed power directly to the gas turboset auxiliary power supply busbars can be provided. The generator rating required for normal start-up of a Model V84 or V94 gas turboset by means of its variable-frequency converter is approx. 1900 kVA. The 1700 kW diesel generator is packaged together with the fuel-oil storage and forwarding equipment within a pair of containers which can be located anywhere near the gas turbosets. By connecting the fully automatic diesel generator to the intermediate-voltage busbars in each gas turboset PCC, it can be used to start up any one of the gas turbines in the plant in the event of an external system failure.

Electronic Control, Automation and Protection Systems

The cabinet row in the first container encloses all the electronic hardware to control automatically the gas turboset and to protect the entire gas turbine unit including the associated power transformers.

The turbine controller employs Iskamatic hardware. This long-established Siemens solid-state system possesses the necessary very high speed of response of less than 10 ms for satisfactory turbine regulation to be achieved.

Fig. 3 - Lay-out of completely factory-pretested equipment belonging to a gas turboset PCC installed within three separate bolted-together containers.

Fig. 4 - Side view of the first (above) and the second (below) containers of a standard gas turboset PCC with the partition walls and some door panels removed.
The heart of the MICOS concept lies in the turboset automatic control and protection system. It represents a special application of programmable microprocessor-based AS 220 EHF and E automation stations belonging to the Siemens Teleperm ME process control system for various power plant applications /4/. The AS 220 EHF station fulfills the most stringent requirements in regard to operating security by means of two-out-of-three redundancy and fault-tolerant design of the central processing units (CPU). These units process all protection-circuit signals internally with a two-out-of-three, two-out-of-two or one-out-of-two redundancy at the process interface depending on the importance of the signals for overall reliable operation of the functional-area equipment (Figs. 5 and 6). No fault within the three redundant CPU can cause nuisance tripping (active faults) or block tripping required by the process (passive faults). The fault-tolerant and fail-safe features of the AS 220 EHF automation station with a mean time between failures of 10^8 hours ensure maximum turboset operating reliability and availability. Since the capacity of this highly redundant signal processing equipment is limited, an additional AS 220 E automation station with a single CPU is employed to process those signals which have minor impact on gas turboset operating reliability. Failure of any Teleperm ME modules is signalled and, in the case of the AS 220 EHF automation station, these can be replaced on line without disrupting gas turboset operation.

Both automation stations (AS 220 EHF and E) are dedicated to the control of all the equipment within the gas turboset functional area. They are provided with sufficient extension units in the form of plug-in cards which make up an input/output level processing the analog and binary signals to and from all the open and closed-loop controls, as well as the protection circuits. A mobile structuring unit permits automatic functions to be implemented by installing, linking or activating standardized software elements.

The equipment belonging to the gas turboset functional area is organized as a single functional subgroup or loop with sequentially controlled subloops which control the power generation process. This functional-subgroup automation directs the start-up of the gas turboset from zero or turning speed through synchronisation to loading up to any preset level.

The protection of the gas turboset functional subgroup is implemented in the main automation station (AS 220 EHF) due to its highly reliable and fail-safe design features. High reliability means in this case that any failure in the functional area normally cannot cause any operational disturbance unless the functional subgroup control design necessitates at worst a justifiable curtailing of power output. Failure safety signifies, on the other hand, that any such failure cannot give rise to potentially dangerous operating conditions or to any adverse effect in regard to the integrity of the provided safety and monitoring functions. Both these important criteria are fulfilled by MICOS with its supplementary circuits for failure recognition and failure correction.

The protective logic circuits in the AS 220 EHF automation station are all executed three-fold and screened by two-out-of-three voting modules. The signals from the functional-area equipment required for protection purposes are fed redundantly to the input/output level either through two or three separate channels depending on the importance of the function. These signals are connected in accordance with the design redundancy to individual plug-in cards in different process-interface

Fig. 5 - Block diagram of an AS 220 EHF automation station for highly reliable and fail-safe functional-group and subgroup control automation.

Fig. 6 - Each AS 220 EHF automation station is contained within three cabinets with its three central processing units to the left of the extension units for the process signal input/output level.
sections. In the event of any disturbance in a safety-related channel, e.g. failure of a process-interface section, input/output card or peripheral device, such as a transmitter, the integrity of the protective function is preserved by means of automatic restructuring of the original two-out-of-two or two-out-of-three redundancy to single-channel or one-out-of-two circuitry. In addition to various failure recognition and correction techniques, special monitoring functions, e.g. analog comparisons, are performed. They compare analog signals in different channels from the same measuring point so as to monitor any deviations in magnitude. Should an impermissible differential be detected, the protective circuitry is automatically restructured to eliminate the spurious-signal channel.

Key criteria, e.g. speed, electric output, etc., which are used to initiate various steps in the automated functional-subgroup control of the gas turboset, are also processed by the protective logic to a degree of security commensurate with their importance for overall operating reliability and availability. Furthermore, required variable trip-delay time periods are formed and functional correlation checks are performed for the protection circuits in the CPU of the AS 220 EHF automation station. A signal is outputted to the annunciating system whenever a protective limiting value is exceeded so as to allow corrective countermeasures to be taken by the operator before an even higher value forces a trip.

The electronic generator and transformer protection system comprises plug-in subsystem modules for the individual protective functions, e.g. generator and transformer differential and overcurrent, generator overexcitation and ground-fault protection /5/. Their contacts act directly on the appropriate 220 V d.c. control circuits.

Local Control Panel

The functional-area local control panel (Fig. 7) is located at the end of the row of electronic hardware cabinets in the first container. This panel has all the conventional control elements, indicators, recorders and annunciators, which are hardwired to the appropriate process interface plug-in cards, to permit an operator to gain a full insight into the running performance status of the gas turboset and to alter it manually at any time. It can also be equipped with fuel-gas and/or fuel-oil consumption meters.

The operator can also initiate and supervise automatic start-up and operation of the gas turboset from the local control panel. He can override the automatic sequential control of the gas turboset functional-area equipment in any desired respect permitted by the protective logic. If any operational function should fail he can also intervene by issuing commands in order to allow the automatic sequential control to resume its programmed task. The local control panel thus affords a redundant command level with respect to the MICOS automation equipment.

A small data-logging printer is also included in the local control panel. Any internal faults which occur within the AS 220 EHF and E automation stations are printed out in coded form in chronological order. A separately mounted large printer is also provided to allow not only any such internal faults, but also all switching events in the gas turboset functional area to be logged chronologically in clear text. The selection and typing of those occurrences, which are desired to be timed and stored prior to being printed out, is accomplished by the external structuring unit.

**COMBINED-CYCLE POWER PLANT**

**Bottoming Steam-Cycle Power Control Centers**

In the case of a GU 2.84 or 2.94 block two Model V84 or V94 gas turbosets are fitted with exhaust-gas heat-recovery equipment to raise steam for a common bottoming steam cycle complete with steam turboset and possibly also heating-steam cogeneration. This requires the addition of at least four functional areas of mechanical and electrical equipment, namely two for the pair of identical heat-recovery boilers, one for the feedwater and CW supply, and one for the steam turboset with condenser (Fig. 8).

Analogous to the two gas turboset functional areas, each of the functional areas of the associated heat-recovery boilers is furnished with its own containerized power control center. It consists of a single container with a low-voltage transformer and distribution system fed from the gas turboset PCC intermediate-voltage busbar. The electronic control of the functional area is accomplished by an AS 220 EHF automation station.

![Fig. 7 - Upper portion of the local control panel in a gas turboset PCC with all the necessary control elements, indicators, recorders and annunciators to direct the operation of the machine.](https://asmedigitalcollection.asme.org/GT/proceedings-pdf/GT1988/79214/V004T10A005/2398058/v004t10a005-88-gt-221.pdf)
The two functional areas covering the steam turboset and the associated feedwater and CW supply are served by a single two-container PCC. The first container is 4.5 m wide to permit all the low-voltage distribution switchgear, including the cast-resin supply transformer, as also the electronic control and protection equipment together with the d.c. supply systems for both functional areas to be accommodated. Similar to the gas turbosets, the steam turboset functional area is equipped with two automation stations, namely AS 220 EHF and E. Two non-redundant AS 220 E automation systems, however, are sufficient for the functional-group control of the redundant pumps and other auxiliary equipment contained in the feedwater and CW supply functional area. The second container houses the intermediate-voltage distribution with withdrawable motor control centers for the feedwater and CW pumps.

Any remaining peripheral plant sections, e.g. fuel forwarding and/or treatment, water treatment, etc., can be grouped to form a fifth functional area with its own automation station(s). The associated low-voltage supply system and electronic hardware can be consolidated as a PCC in a container or installed in an annex.

A basic difference between the gas turboset and other PCC is that the latter are not furnished with local control panels because the functional areas of the bottoming steam cycle cannot operate independently of the gas turbine(s). Even after the addition of exhaust-gas heat-recovery equipment each of the gas turbosets can, however, be run on its own in simple cycle provided that it be equipped with a bypass stack. This simple-cycle capability justifies the provision of a local control panel which can serve as the sole control location before conversion to combined-cycle operation by the addition of a bottoming steam cycle.

Automated Operation and Protection

As in the case of the gas turboset functional area, the automation stations dedicated to each of the other functional areas ensure highly reliable functional-group and subgroup control automation of all the mechanical and electrical equipment involved in the exhaust-gas heat-recovery and steam turbine power generation processes.

The automation stations in all the PCC belonging to a GUD block are interconnected by means of a redundant remote (local area network) bus system (Fig. 9). The data interchange is itself supervised. The bus control is decentralized and the "flying-master" principle is applied. A maximum of 32 users, i.e. automation stations, as well as operating and monitoring systems, can be connected to this bus system.

Since combined-cycle plants are not only base-loaded to maximize the benefit of their high operating efficiency, but on account of their operating flexibility are also frequently two-shifted to satisfy midrange-load demands, a high degree of overall GUD block automation is normally provided. The example of a cold start-up of a typical block (Fig. 10) is used to outline the extent of such automation as follows:

- manual preparation of the plant for start-up by switching on various subloop controls so as to start the pumps required to fill the water circuits. At the same time the feedwater in the deaerator tank should be heated up by means of the auxiliary steam boiler.
- automatic placing of steam condenser and turbine auxiliary equipment in service.
- automatic start-up, synchronizing and loading of first gas turbine (GT 1) in simple-cycle operation to a preset load level.
- automatic commencement of feedwater circulation with subsequent gradual opening of the associated boiler damper. Once the resultant steam has attained a certain pressure level (at least 2 bar), the HP and LP steam bypass valves are automatically opened.
- automatic step-by-step closing of the associated gas turbine exhaust-gas bypass damper. When the steam has an adequate temperature it is used to prewarm the HP and LP steam pipes and turbine inlet valve casings.

The diagram of a GUD 2.84 or 2.94 power plant divided into six functional areas of equipment of four different types.

Fig. 8 - General system diagram of a GUD 2.84 or 2.94 power plant with functionally distributed automation stations and superimposed central control room.

Fig. 9 - MICOS block diagram for a GUD 2.84 or 2.94 power plant with functionally distributed automation stations and superimposed central control room.
- automatic start-up, synchronizing and loading of the steam turboset. The output is raised as fast as the casing and rotor thermal stresses (steam turbine stress evaluator) allow.

- automatic closing of the HP and LP steam bypass valves as soon as the turbine can accept the full steam output from the boiler. The gas and steam turbosets can now be further loaded in a coordinated mode without any steam being bypassed to the condenser.

- when required, operator can initiate automatic start-up of the second gas turboset (GT 2) and associated boiler. Before the second boiler is allowed to feed steam to the HP and LP headers, the output of both gas turbosets should be equalized to ensure balanced outlet steam temperature and pressure levels. After the second boiler has been connected to the HP and LP steam headers, the steam pressure is ramped further in accordance with preset gradients until the turbine is correspondingly loaded and the steam bypass valves associated with the second boiler are also fully closed.

The coordination of all the above steps is accomplished by an overall block integral control scheme (Fig. 11). The actual start-up performance is illustrated by typical measured gas and steam turboset output ramps, as well as steam-pressure and material-temperature gradients (Fig. 12). The dotted lines indicate the time period within which the second gas turboset must be fully loaded for the bottoming steam turboset to reach full output, as shown without unnecessary delay.

The steam turbine with full-arc admission is operated in the variable-pressure mode. Its output is not regulated because it results automatically from the production of steam from the available exhaust-gas heat, i.e. from the combined output of the gas turbines.

The HP and LP steam header pressure levels to achieve the anticipated steam turboset output are computed on the basis of the variable-pressure characteristic. Corresponding limits are imposed on the boiler outlet-pressure regulators (steam bypass station setpoints) and on the HP and LP steam turbine initial-pressure regulators. Once the steam turbine has accepted the full flow output of the boiler superheaters, the steam bypass valves are closed fully and kept in readiness to reopen whenever necessary, e.g. a sudden load reduction.

A minimum gas turboset output is required for combined-cycle operation so as to avoid excessive moisture in the steam being admitted to the bottoming turbine. The exhaust-gas temperature at full load is maintained down to about 65-percent load by gradually closing the variable-pitch initial guide vanes of the gas turbine compressor. If only about half the capability of a GUD 2.84 or 2.94 block is required, it is generally preferable to run one of the gas turbosets for short time periods at higher than base load (release GT 1 for overload) than to operate both gas turbosets around the half-load mark.

The load contribution of each gas turboset is determined from the preset GUD block output requirement taking into account the anticipated resultant contribution of the steam turboset. The results of this cal-

Fig. 10 - Typical dual-pressure GUD 2.84 or 2.94 power plant equipment consisting mainly of a pair of two-stage heat-recovery steam boilers with flue-gas pre-heating of the condensate and a dual-admission condensing steam turbine.

Fig. 12 - Typical measured start-up performance of a GUD 2.94 block following a 48-hour (weekend) shutdown.
work stations each with process-control keyboards and color VDU screens. The operators' desk features two separate autonomous controllers of the gas and steam turbosets, as well as to the steam bypass station regulators. The function keyboards and VDU belong to the double re-vated VDU with color screens. The control tiles in the console are hardwired to the Iskamatic turbine con-trrollers. These back-up controls allow the operators to start and stop the GUD block by manually initiating the principal steps in the automated start-up and shutdown sequential-control procedures in the event that the redundant operating and monitoring system not be avail-able.

Central Control Room

The control room of a combined-cycle power plant is, of course, best situated in a centrally located building. The use of human-engineered function keyboards and color VDU screens, which allow operators to communicate with the MICOS equipment in the various PCC located throughout the station via the redundant remote (local area network) bus system, facilitates building the control room in a very compact fashion. This operator interface gives the supervisory personnel at all times an in-depth insight into the operational status of the entire plant and its individual sections /6/. With such detailed information at their command, operators can intervene rapidly with confidence whenever abnormal service conditions necessitate counteractive measures, thus contributing to high overall operating reliability and availability of GUD blocks.

The operators' desk features two separate autonomous work stations each with a process-control keyboard (Fig. 13). It is also equipped with three or four ele-vated VDU with color screens. The control tiles in the console are hardwired to the Iskamatic turbine con-trollers of the gas and steam turbosets, as well as to the steam bypass station regulators.

The function keyboards and VDU belong to the double re-dundant operating and monitoring system which is super-imposed on all the AS 220 EHF and E automation stations in the plant (Fig. 9). Each of the two parallel systems shows identical representations of the GUD functional areas. These include:

- normalized functional-group and subgroup control displays showing relevant groups of control tiles and instruments,
- functional-diagram displays of sequential start-up/shutdown programs,
- trend displays,
- alarm-sequence displays, and
- plant mimic-diagram status displays.

The last two listed types of displays are illustrated (Fig. 14) as examples of the formats in which information is readily available to the control-room operators on request by means of the function key-boards.

During trouble-free operation the functional areas for the gas turbosets and associated heat-recovery boilers are generally allocated to System 1 of the operating and monitoring system. System 2 is then used to operate and monitor the functional areas covering the feedwater and CW supply, as well as the steam turboset with condenser.

Behind the operators' desk is a panel with a complete mimic diagram of the combined-cycle block. It is furnished with conventional control-room equipment, viz. control tiles, indicators, recorders and annunciators. All these devices are hardwired to the appropriate input/output level (process interface) plug-in cards of the decentralized AS 220 EHF and E stations. Hence they are entirely redundant since the same information is available through the softwired operating and moni-toring system, and the same control functions can be initi-ated from the operators' desk. The control tiles in this conventional operator interface are, however, limited to switching on and off the various automated functional groups and subgroups, as well to altering the settings of the main closed-loop (modulating) regu-lators. These back-up controls allow the operators to start and stop the GUD block by manually initiating the principal steps in the automated start-up and shutdown sequential-control procedures in the event that the redundant operating and monitoring system not be avail-able.

To one side of the operators' desk is another smaller panel with a mimic diagram of all the miscellaneous station auxiliary services (fifth type of GUD func-tional area), e.g. water and possibly also fuel treat-ment, fuel forwarding, etc. Although they are usually
also controlled by an AS 220 automation station(s), they are not integrated into the GUD operating and monitoring system. This is because their operation can be controlled independently of the combined-cycle power generation process. For this reason all the controls, measured values and alarms are hardwired to the control room, indicators and annunciators so that the operators can control these station ancillary systems remotely in the conventional manner.

Other standard equipment in the control room includes a data logger. All the switching events and alarms that occur in the GUD functional areas can be logged in chronological sequence and in clear text by a large printer in the control-room annex. Supplementary optional equipment is a process computer which can communicate with the remote bus system. It can be employed to augment the operating and monitoring system by compiling, for instance, operating logs, daily balance logs, analog-value status and trend logs, post-incident reviews, etc. It can also be usefully applied to computing overall GUD thermal performance so as to help the operators maintain high station operating efficiency.

CONCLUSION

The modular design of GUD stations in the form of package-engineered mechanical and electrical equipment for each of the five types of well-defined plant functional areas provides the flexibility needed to optimize the combined-cycle process and equipment for each individual application which varies greatly depending on the fuel(s), prevailing site conditions and operating requirements. The containerized PCC permit the electric power supply systems together with the MICOS electronic hardware to be located in close proximity to the mechanical and electrical equipment they feed, control and protect. This functional distribution or decentralization of the MICOS electronic hardware simplifies the automated control and protection schemes and allows GUD blocks to be readily built in phases, first the gas turboset(s) followed by the bottoming steam turboset. The local control panel supplied in the PCC for each gas turboset facilitates simple-cycle gas turbine operation before any exhaust-gas heat-recovery equipment is added or a central control room exists.

The modular design approach to the mechanical and electrical equipment and partially standardized PCC help to shorten the delivery times. Since the PCC containers are weatherproof and internally air-conditioned, they can be installed equally well outdoors as indoors. This fact allows considerable flexibility in laying out GUD stations to suit different station-design preferences. Especially the completely preassembled and pretested containerized PCC minimize the necessary field installation man-hours and accelerate the final commissioning of all the plant equipment on site. These design concepts and assembly pretesting techniques should promote such unfired combined-cycle installations with their unsurpassed overall economy to become the most favored form of electric power generation from liquid and gaseous fossil fuels.

REFERENCES


