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FOREWORD

The Power Industry Division of the Instrument Society of America is dedicated to serving engineers, technicians, and managers in the exchange of technical knowledge and expertise in the areas of controls and instrumentation in the Power Industry. The annual symposium is the major forum for presentation and discussion of our industry's experiences, challenges, and solutions.

Ten years ago, an event occured which has had a profound effect on the entire world. The oil embargo of 1973 has resulted in major changes within our industry, and presented many significant challenges to the controls and instrumentation sector.

The theme of this symposium is "The Oil Embargo—Ten Years Later." The papers presented deal with topics relating to the response of the Power Industry to the changing environment under which it now finds itself. Sessions were developed dealing with programmable controllers and logic systems, control simulation and tuning, human factors engineering, controls and instrumentation modernization, the impact of TMI on Regulatory Guide 1.97, and alternate energy systems.

The papers presented and included in these proceedings document actual experiences, present practices and future trends of the power industry. Included in these proceedings is the student paper presented at the symposium by the 1983 recipient of the POWID Achievement Award scholarship, which was well received by attendees.

It was evident from the papers presented and discussions that the utility industry has been and will continue with optimization and modernization of existing power plants in this era when new plant construction has nearly stagnated. Instrumentation and Controls are at the very heart of these efforts as witnessed at this and recent POWID symposia. No other equipment or system in the power plant have experienced the tremendous growth that we in this facet of our industry have been priviledged to be a part of.

The 26th Annual Power Industry Instrumentation Symposium has to be considered a success, thanks to the efforts of Session Developers, Authors, Host Committee, and many others who contributed their time and efforts to make it so. As we enter the second quarter century of progress, we look forward to continued successes from the sharing of experiences, thoughts and knowledge by our peers at future symposia.

Ted C. Reitz
Program Chairman

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ABSTRACT

Power plant generating costs demand that utilities achieve the highest availability and efficiency possible. Gibbs & Hill, Inc., anticipates that the 500-MW coal-fired generating plant it designed for Soyland Power Cooperative could achieve increased availability because of the unit's highly automated control system. The increase in availability due to this control system could result in large savings the first year alone. This paper describes the decentralized, distributed, hierarchical microprocessor-based control system we designed, discusses some of the design problems we encountered, and outlines the Binary Control and Automation System's major benefits. It is not the intent of this paper to explain the detail engineering, but only to describe the overall concept of this system.

INTRODUCTION

Although this 500-MW coal-fired generating unit has been deferred for the present, over the past two and one-half years we have gained valuable experience in power plant automation techniques. In the spring of 1981, our client purchased a decentralized, distributed, hierarchical microprocessor-based control system as an extension of the automation controls of the turbine-generator (1). The Binary Control and Automation System (BCAS) has the responsibility to start up, supervise, and shut down the steam generator, turbine-generator, and their auxiliaries automatically. By automating the plant to such a degree, the utility expected to increase overall plant availability, efficiency, and operational safety. Designing a plant with such an innovative control system presents the engineer with unique challenges and problems. Because other engineers undoubtedly are or will be faced with similar undertakings, we would like to discuss the benefits of the BCAS and the problems we faced, and describe the system itself.

Experience of the BCAS Manufacturer

Since 1961, the BCAS manufacturer contracted for this project has automated over 165 turbine-generator sets and over 30 steam generators (2,3) to varying degrees. Although this manufacturer had extensive automation experience, the company has not automated a coal-fired plant in the United States to the degree intended for this generating facility. Consequently, at the REA's request, we visited the BCAS manufacturer's facilities in Europe, several European power stations including the Amer 10 power plant (4) in the Netherlands, and the world's first compressed-air storage plant (5) at Huntorf, Germany, to verify firsthand the claims and benefits of the BCAS. The European utilities we visited claimed that they had never experienced the need to operate their entire power plant manually because the automation package was highly distributed and had never failed as a whole.

BENEFITS AND CONCERNS

Benefits

We found that the BCAS has the potential to offer the following major benefits:

- The BCAS can reduce operator decisions and errors during emergencies because the appropriate responses are preprogrammed into it.
- The system starts up and shuts down plant equipment the same way each and every time, thereby extending equipment life by avoiding or greatly reducing the mechanical and thermal stress and damages that result from inconsistent and improper operating procedures and practices (7).
- The BCAS can, in conjunction with the turbine bypass, provide substantial fuel savings because it allows faster run-up times and lower run-up losses (7).
- Operator manual override is available at all times and at each level of the BCAS (2) hierarchical structure.
- The BCAS is distributed and modularized for high system integrity, reliability, and ease of maintenance. The modular configuration also provides for standardization of electrical schematics and terminations.
- The remote multiplexing system supplied with the

BCAS provides for cable control and raceway savings.

- Most important, the BCAS offers significant financial benefits due to the potential to increase plant availability. According to EPRI statistics (1) and power authority experts (8), an increase in plant availability is not only realistic but is more achievable with the aid of increased power plant automation. In our commercial evaluation, we found the direct costs of the BCAS comparable to the costs of conventional unautomated power plant control systems. A utility does incur additional indirect costs with the BCAS because of an increase in the number of power-operated valves, process instruments, vendor standard package changes, interface requirements, and engineering and design man-days. These indirect costs, however, are offset by increased generating revenue from greater plant availability and decreased construction and start-up problems. This potential benefit could amount to $3,200,000 for the first year of operation, assuming plant availability is increased by 2%, with additional higher savings thereafter. The appendix illustrates the potential cost savings.

Concerns and Considerations

Our primary concern was the additional engineering and design man-days required to coordinate, interface, input information, review, analyze, and implement the BCAS. Basic everyday concerns included project control, scope of supply, responsibilities, liabilities, and project scheduling problems. Other concerns had to do with the BCAS manufacturer's differences in philosophy concerning American instrumentation and power industry standards, codes, practices, drawing symbols, and format and presentation.

Interface Requirements

To address interface requirements, concerns, and considerations, we found it essential that the client, engineer, BCAS manufacturer, and other plant equipment manufacturers early on establish the responsibilities, rules, and guidelines necessary to facilitate and expedite BCAS engineering and design. The engineer must ensure that the responsible party:

- Prepares a detailed specification for the BCAS manufacturer, defining his scope of supply and responsibilities.
- Establishes communication guidelines among the engineer, the BCAS manufacturer, and other equipment manufacturers.
- Establishes that all interface signals between the BCAS manufacturer and other control systems be via dry contacts and/or 4-20 mA dc only to prevent protocol problems.
- Establishes procedures for amending equipment contracts to accommodate requirements of the BCAS.
- Prepares a section for insert into all equipment specifications defining the interface required among the engineer, BCAS manufacturer, and other equipment manufacturers. Each section should be as detailed as possible and customized for that particular equipment manufacturer.
- Prepares a project schedule of preliminary and subsequent engineering and design documents for exchange among the engineer, the BCAS manufacturer, and other equipment manufacturers. See Table I.

A final concern is that the plant operating personnel will rely on the BCAS so much that they may experience difficulties when operating in manual.

Further considerations should be given to ensure that the following items are furnished:

- Detailed operating instruction manuals for the BCAS.
- Detailed control system description for the BCAS.
- Training program for the BCAS.
- Complete functional system testing of the BCAS.

A DESCRIPTION OF THE BCAS

The BCAS scope of supply for this project includes the following plant systems: data acquisition and monitoring computer, burner management, unit protection, solid-state interlock, annunciation, remote multiplexing, and the plant automation.

The BCAS automates all operator actions during the following main operating phases:

- Start-up of the unit steam generator, turbine-generator, and their auxiliaries.
- Response to operational disturbances (that is, a deviation from a stable operating condition that requires an operator or the BCAS to take action or to restabilize the process; for example, automatic start-up of the standby pumps upon failure of primary pumps).
- Shutdown of the unit. The shutdown phase specifically includes establishing the state of the power plant to allow for a fast restart once the plant equipment has been secured.

The Decentralized, Hierarchical Automation Structure

The decentralized, hierarchical automation structure is the most important concept of the BCAS. This concept is similar to the organization of a company. The president issues directives to his managers, who in turn relay the orders to their workers as necessary (9,10). Figure 1 illustrates the automation structure.

The lowest level of the hierarchical structure is the drive control. A drive is either motor-operated equipment (pump, fan, valve, damper) or solenoid-operated equipment (valve or damper). The BCAS controls and monitors the plant drives, which are provided in other equipment manufacturers' scopes of supply. Figure 2 depicts the interface between the BCAS and other vendors' equipment. Figure 3 shows typical drive controls. In this automation system, each drive can be started manually or automatically. Each drive has its own interlocks and protection preprogrammed in its own microprocessor, thus ensuring independent safe operation at this level.

The functional group control is the next level in the hierarchy. Here drives are grouped functionally with the sequencing between each drive preprogrammed in its own microprocessor. For example, the condensate pumps are grouped with their respective discharge valves to operate together. The BCAS also has the capability to start this group manually or automatically.

The highest level of the hierarchy is the unit control. This level combines the functional groups to operate as a unit with the sequencing between each functional group programmed in its own microprocessor (i.e., boiler, turbine-generator, feedwater, condensate, etc.).

The BCAS is geographically decentralized to minimize unnecessary information flow from the control room and increase overall system reliability. The drive control level is physically located near its process in cabinets and rated to operate from 0°C to +70°C and 95% noncondensing relative humidity for a continuous 30-day period. Hierarchical decentralization of the system offers the following advantages:

- The system is functionally subdivided into recognizable modular subsystems that operators and maintenance personnel can easily identify.
- A malfunction or fault will only affect a specific piece of equipment or very limited portion of the system.
- If the system cannot operate at the higher levels, the lower levels can be operated independently (i.e., if a limit switch causes the automation sequence to halt, after identifying the problem, a lower level drive can be started to initiate and continue the automatic sequences).
- Reduced electrical wiring as is typical of any remote multiplexing system.

BCAS Modular Hardware

The BCAS hardware is based on a digital, programmable, sequential control system. It features various modules for processing measured variables (digital and analog control), data transmission (communication between man and the control and monitoring system), and processing modules equipped with microprocessors (10,11). Except for those modules mounted directly in the auxiliary control panel (ACP), the boiler turbine-generator console (BTGC), and electronic equipment room logic cabinets, the remaining modules are configured into remote multiplexing stations (RMS) that are placed near the process, as shown in Figure 2. For example, an RMS placed near a switchgear cubicle will typically contain drive modules and interface relays to control the breakers. An RMS on a boiler platform will typically contain input modules for thermocouples. Most modules are standard with built-in logic. The processing modules are programmed locally, using a hexadecimal code for instructional input.

Remote Multiplexing

The BCAS features a remote multiplexing system consisting of a local bus (located in the cabinets) and an intra-plant bus (located throughout the plant). All signals are interrogated cyclically and transmitted successively via the intra-plant bus system. Each signal transmitted is identified by a unique address tied to its origin. Data transmission via the bus system is in the form of a telegram. A telegram comprises an address word and information word, each 17 bits. A total of 16,384 addresses is possible per channel. The information bit rate per channel is 156 K bits/s. The approximate scan cycle time per digital signal is 13 ms and per analog signal is 26 ms.

All modules can communicate with any point in the process via the local and intra-plant busses. The intra-plant bus utilizes three dual channels: channels A and B for the turbine-generator and its auxiliaries; channels C and D for the boiler, feedwater, and their associated auxiliaries; and channels E and F for the pulverizers and their associated auxiliaries. Each channel consists of two coaxial cables, connected to redundant address transmitters at each station, and each cable is run in a separate path (dedicated conduit or duct). See Figure 4.

Cross-talk between dual channels is done via bus coupling modules. Cross-talk between intra-plant busses uses the same technique or the interface signals can be hardwired between an output module on one bus to an input module on another bus.

Each RMS has a 125-Vdc and a 120-Vac power supply from the plant inverter. The incoming voltages are converted to the required system internal voltages, and are diode auctioneered to form a highly reliable power supply.

Data Acquisition and Monitoring Computer

The process computer as a component of the automation concept provides the operating personnel with concentrated, closely defined information on CRT displays, and records and analyzes data (12). Eight color CRT displays are used here to show traditional boiler and turbine data, such as recording functions, system mimic diagrams, and calculation functions. This computer system differs from conventional computer systems in two major ways: 1) it communicates directly with the three dual channels' intra-plant busses and 2) it provides additional presentation of control sequence diagrams and criteria indication. In addition, printers, recorders, video copiers, and magnetic tapes serve for long-term storage and retrieval of plant data (13,14).

The control sequence diagrams and criteria indication depict the automatic sequential control system for start-up and shutdown, disturbances, or nonfulfilled criteria. In the case of manual operation, the CRTs display criteria that must be fulfilled by the operators to place equipment in and out of service.

Push-Button Modules

The BTGC and ACP utilize a modularly assembled grid structure for supporting mosaic tiles and miniature push-button modules (PBMs). The PBMs are plug-in type units. They can be removed from the front of the panels, with the plug portion prewired to the electronic modules. The modules are mounted as an integral part of the BTGC and ACP, and are connected to the appropriate intra-plant bus. The PBMs consist primarily of two push buttons and three light-emitting diodes (LEDs), rated for 24-volt DC operation, as shown in Figure 3. All push-button operations are momentary, and require that an associated release push button be depressed to prevent inadvertent operations. The release push buttons are strategically placed in appropriate sections of the BTGC and ACP for ease of operation and accessibility. The LEDs are used as a part of the BCAS's self-diagnostic system. Through flashing and audible signals, the LEDs inform the operator of various disturbances and equipment status (10). See Tables II and III.

Alarm System

The prioritized overhead alarm system (OHA) is designed to reduce the number of alarm windows and minimize nuisance alarms and operator confusion. The OHA is a backup to the CRT-displayed alarms and consists of 255 windows arranged on the top of the ACP to correlate with the process. We have prioritized the alarms into three categories comprised of critical alarms, urgent alarms, and operational alarms.

They are placed from top to bottom in a row on the annunciator window boxes, and are colored red, amber, and blue respectively, as defined in Table IV. The OHA system is integrated with the disturbance and status alarms appearing on the PBM and the alarms displayed on the CRTs in a manner that reduces confusion and enables the operator to take prompt and proper action.

Since all alarm inputs are located on the intra-plant busses, we intend to have the OHA sequence logic accomplished by the BCAS, eliminating the need for separate OHA logic cabinets and reducing the amount of different hardware. See Table V for more information.

Control Room

The control room provides the operators with decision-making aids so that they can intervene selectively in the process events to prevent failure and increase plant availability (15,16). Current human factor engineering techniques have been a prime consideration in the design of this control room. With the BCAS, the power plant personnel will perform mainly supervisory functions, set reference values, prevent disturbances, trouble shoot, and provide maintenance.

The control room, which requires two operators, has been designed for all unit and functional group-level controls from the BTGC. All drive-level operations are performed at the ACP. Shown in Figure 5, the control room encompasses the BTGC, ACP, the plant monitoring desk (which contains three printers, a video hard copier, a telephone, and the plant security monitoring system), the supervisor's office, kitchen, bathroom facilities, and the computer room.

The BTGC is a sit-down console comprising three sections. The left section consists of boiler functional level and manual/auto control stations and three CRTs; the center section consists of unit-level controls and two CRTs dedicated for alarms; and the right section consists of turbine-generator functional-level controls and three CRTs.

The ACP has all drive-level controls and associated indicators in the appropriate position on an extensive mimic representing the plant systems.

Controls from left to right match the BTGC with the center part of the ACP reserved for recorders. The upper part of the ACP is angled and holds the OHA window boxes.

The BTGC and ACP have the man-machine interface modules mounted as an integral part of these panels. The modules are connected to the appropriate three dual intra-plant busses. This innovative design saves the client over 2,000 cable runs, and eliminates the usual congestion associated in the cable spreading room, thereby also reducing fire hazards.

The computer room is glass enclosed and faces the control room. It houses the CPU cabinets and the engineer's and programmer's desk, as shown in Figure 5.

The electronic room is located in the back of the ACP on the same floor as the control room. It includes the main turbine logic and supervisory cabinets, some BCAS logic and interface cabinets, the boiler feed pump turbine control and supervisory cabinets, the generator protection cabinets, the coordinated control system cabinets with associated engineering console, the BCAS diagnostic station, and any other required miscellaneous control logic and equipment supervisory cabinets.

Trouble-Shooting and Maintenance

The BCAS control system hardware is designed to facilitate testing and maintenance. If a component failure occurs on a module, the failure is alarmed and identified on the BCAS diagnostic station. Simultaneously, a lamp is energized on the outside of the RMS containing the failed module, and, in addition, a LED is energized on the malfunctioning module itself.

This procedure allows quick identification of the failed module so that personnel can locate and replace it quickly, returning the affected control loop back to automatic.

The diagnostic station, located in the electronic room, consists of a CRT, two printers, an operator keyboard, and a magnetic tape-cassette system. The station indicates and logs all disturbances within the BCAS in a clear text. With this information, the operator can diagnose quickly the type and location of the disturbance.

CONCLUSION

We were fortunate to have had the opportunity to be involved in the design of what could be the most automated power plant in the United States, and we are grateful for the invaluable engineering experience we have gained. We do not necessarily advocate such a high degree of automation for every generating unit. We do predict, however, that as high availability and reliability become mandatory, utilities will move toward automated control systems as one method of achieving these goals.

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APPENDIX

POTENTIAL COST SAVINGS FROM THE BCAS

The use of a BCAS does not necessarily mean that a utility will realize a cost savings. The exercise below merely shows the potential cost savings possible if the automation system increases plant availability by 2%. While this 2% increase is not unrealistic, no data exists to prove it is a certainty. In addition, direct proof of increased availability would be hard to correlate because power plants are not identical nor do they run under exactly the same conditions.

OBJECTIVE:

To show the possible cost savings that could be realized by utilizing a plant automation system to increase plant availability.

CRITERIA AND ASSUMPTIONS:

(1) The automation system increases plant availability by 2% at a service factor of 70% per year.

(2) The 1981 cost of electricity from another utility is \$.04 ¢/kWH including discounts.

(3) The estimated cost of the plant is \$810,000,000 (1987).

(4) The fuel cost is \$1.54 per million Btu, 10% interest rate, and 8% fuel escalation rate.

(5) The Btu value of coal is 10,500/lb.

(6) The 450-MW net avg. heat rate is 10,750 Btu/kWHR.

(7) The start date of operation is mid-1987.

(8) Cost savings = cost to purchase replacement power + fixed charge on borrowed cost of plant - cost to generate power
$= C_P + C_{FX} - C_G$

(9) Indirect costs caused by the BCAS are offset by the solutions to many construction and commissioning problems discovered during the extensive analysis of the plant process systems during the plant automation engineering and design phases.

(10) Direct cost of the BCAS equipment on this particular unit is comparable to the cost of conventional, unautomated power plant systems.

(11) Maintenance and operating costs are not considered.

(12) Equipment repair costs and fuel-saving costs were not considered.

COST TO PURCHASE REPLACEMENT POWER:

$C_P = 450{,}000 \text{ kW} \times \$.04/\text{kWH} \times (1 + .08)^6 \times 24 \text{ H/Day}$

$C_P =$ \$687,000/Day (Rounded off)

FIXED CHARGE ON BORROWED COST OF PLANT:

Compound interest of 10% for 30-year plant life for following:

Capital Recovery Factor	= .106	
Insurance	= .003	(Engineering Judgment)
Miscellaneous	= .005	(Engineering Judgment)
	.114	

$C_{FX} = \dfrac{\$810{,}000{,}000 \times .114}{365 \text{ Days}} =$ \$253,000/Day (Rounded off)

COST TO GENERATE POWER:

Cost of Coal $= \frac{\$1.54}{10^6 \text{ Btu}} \times \frac{10{,}750 \text{ Btu}}{\text{kWH}} = \$.0166/\text{kWH}$

$C_G = 500{,}000 \text{ kW} \times \$.0166/\text{kWH} \times (1 + .08)^6 \times 24 \text{ H/Day}$

$C_G =$ \$317,000/Day (Rounded off)

COST SAVINGS AT 100% SERVICE FACTOR:

Cost Savings $= C_P + C_{FX} - C_G$

Cost Savings $= \frac{\$687{,}000 + \$253{,}000 - \$317{,}000}{\text{Day}}$

Cost Savings = \$623,000/Day (First Year)

COST SAVINGS WITH 2% INCREASE IN AVAILABILITY AT 70% SERVICE FACTOR:

Cost Savings = .02 x .70 x 365 Days/Yr x \$623,000/Day

Cost Savings = \$3,200,000/Yr (Rounded off)

NOTE: The above cost savings indicates only first-year savings. Additional savings for each year thereafter are escalatable over the life of the plant.

TABLE I

TYPICAL DOCUMENTATION EXCHANGE

BCAS Manufacturer	Other Equipment Manufacturers	Engineer
Functional control diagrams	Electrical schematics	General and/or plant equipment arrangement drawings
Electrical interface requirements	P & IDs	System flow diagrams
Signal list	Equipment outline drawings	Electrical one lines
Alarm philosophy hardware implementation	Equipment arrangement drawings	Instrument control diagrams
Unit trip protection hardware implementation	Detailed operating, alarming, testing, and tripping instructions and guidelines	Instrument list
RMS documentation	Equipment performance curves	Electrical schematics (typical)
Detailed operating instructions for both automatic and manual modes of control	Bills of material or equipment list	Alarm philosophy
Signal flow diagrams	Logic diagrams	Unit trip protection philosophy
Plant computer documents		Control room arrangement
Electrical connection drawings		RMS electrical connection drawings
Equipment outline drawings		Equipment specification
Equipment arrangement drawings		Cable termination and control power requirements

TABLE II

FLASHING OF TYPICAL NONREVERSING DRIVE PUSH-BUTTON LEDS

Equipment Status	Plant Status	Stop LED (Green)	Center LED (White)	Start LED (Red)
Stationary	Actually STOPPED	○	◇	□
Stationary	Actually RUNNING	□	◇	○
Running	Moving towards STOP	△	◇	□
Running	Moving towards RUNNING	□	◇	△
Disturbances	Was RUNNING, but no longer RUNNING	⬡	⬡	◇
Disturbances	Was STOPPED, but no longer STOPPED	◇	⬡	⬡
Disturbances	Power supply failure or fuse blown (electronics)	□	⬡	□
Disturbances	Other disturbances	◇	⬡	◇
Acknowledgement	Discrepancy acknowledged (otherwise no disturbance)	□	□	◇
Acknowledgement	Discrepancy acknowledged (otherwise no disturbance)	◇	□	□
Simulation	No disturbance, no simulation	◇	□	◇
Simulation	Disturbance or simulation	◇	○	◇
Feedback	Return signal STOPPED available	○	◇	□
Feedback	Return signal RUNNING available	□	◇	○
Feedback	Return signal RUNNING and STOPPED unavailable	△	◇	□
Lamp Test		○	○	○

KEY

○ Lamp continuously lit

□ Lamp extinguished

△ Running status indication (oscillating)

◇ Signalling according to operating state

⬡ Disturbance flashing light

TABLE III

DISTURBANCE AND STATUS ALARMS

Disturbance Alarms a) MCC, SWGR, and solenoid-operated valves - disturbance (loss of control voltage, loss of trip coil, breaker trip, starter loss of control voltage, or motor overload). b) Electronic disturbance (blown fuse) c) Motor-operated valve or damper (overtorqued) d) Simulation (equipment test) e) Local intervention (breaker tripped locally or not in connected position) Status Alarm - Discrepancy (protection trip of a pump, fan, etc.)

TABLE IV

ALARM PRIORITIZATION (OHA)

Alarm Priority	Prioritization Description	Alarm Color
Critical	Highest alarm priority. Requires immediate operator action to prevent impending plant equipment damage, personal injuries, and/or imminent loss of load.	Red
Urgent	Second highest alarm priority. Requires prompt operator action to correct unusual, serious operational, or maintenance situation to prevent an emergency situation from developing.	Amber
Operational	Third highest alarm priority. These are two types of operational alarms, disturbance alarms which require operator response and status alarms which only require the operator's attention to a change of equipment status. In either case, these types of alarms do not present any imminent danger.	Blue

TABLE V

SEQUENCE TABLE

Process Condition	Push-button Operation	Sequence State	Visual Display	Alarm Audible Device	Ringback Audible Device	Remarks
Normal	--	Normal	Off	Silent	Silent	
Abnormal	--	Alarm	Fast flashing	Audible	Silent	Lock-in-manual silence required
Abnormal or normal	Silence	Silenced	Fast flashing	Silent	Silent	Lock-in
Abnormal	Acknowledge	Acknowledged	On	Silent	Silent	Maintained alarm
Return to normal	--	Ringback	Slow flashing	Silent	Audible	Manual silence required
Normal	Silence	Silenced	Slow flashing	Silent	Silent	Manual reset required
Normal	Reset	Normal	Off	Silent	Silent	Manual reset