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Operational simulators and automatic control systems

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Abstract

This paper deals with operational aspects of geothermal projects with focus on control system maintenance and upgrade, and operator training. Various factors affecting the life-cycle cost of control systems are discussed. Considerable reductions in the life-cycle cost of a geothermal project can be achieved through the careful development and implementation of a long-term strategy for the design and commissioning of a new control system and for the upgrades of older control systems. The paper also describes benefits that can be achieved by the application of operator training simulators. The advantages that can be gained by use of simulation techniques in the engineering design of geothermal projects are discussed. The increasing cost of manpower and the decreasing cost of control system hardware has lead to an increase in automation and emphasis on monitoring and control from a remote central control room. Several aspects of this evolvement are discussed.

Keywords: *Geothermal, simulators, training, control system modernization, remote control, maintenance.*

1 Introduction

The lecture describes simulators and automatic control systems which are used for operations by geothermal utilities in Iceland (as well as China and Romania), some of which will be inspected during the IGC 2003 field visits. The lecture is based on the author's experience over 20 years in designing and maintaining control systems for geothermal projects.

2 Simulation

In recent years, the author has used simulation techniques in relation to geothermal utilization in the following areas:

- Operator training simulator for the Svartsengi geothermal plant's new 30 MW_e unit.
- Simulation models used for design studies by the United Nations University Geothermal Training Programme.

Only a brief description of the Svartsengi simulator will be given here, since a separate paper about the simulator will be presented at the IGC 2003 conference.

2.1 Operator training simulators for geothermal power plants

Good operator training is one of the key factors in ensuring high availability of a geothermal power plant. Since the plant can run for extended periods, as long as a whole year, without a shutdown and start-up, the operators rarely get a chance to train critical tasks on the real plant. Operator Training Simulators (OTS) are common in nuclear and large fossil fuel power plants, but the use of an OTS for geothermal power plants is novel. Using the simulator, the operators are trained in start-up and shutdown procedures as well as normal operation and process disturbances handling, including fault finding.

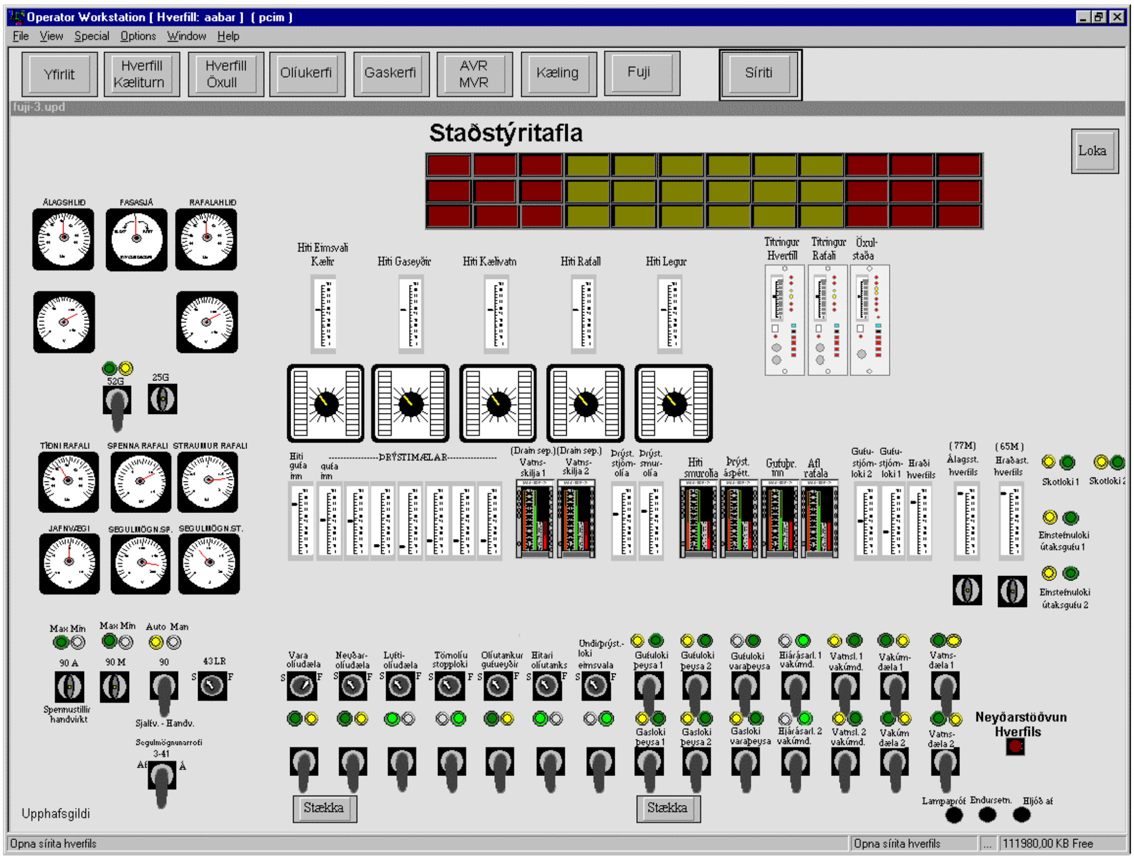


Figure 1: Screen display of a replica of a control panel from Fuji for the 30 MW turbine-generator unit.

Through regular retraining in the OTS, the location of all controls and their functions become second nature to the operators, and they gain a thorough understanding of the connections between sub-processes and the operation of the total plant. The OTS configuration includes a Process Controller and a Man-Machine-Interface that's identical to the one used in the real power plant (see Figure 1). Simulator training reduces the risk of costly mistakes, excessive unit stress and equipment damage. The simulator can also be used for design, evaluation and tuning of the control system, analysis of process design alternatives, and preventive maintenance by comparing real and simulated data.

The use of operator training simulators has been common in nuclear power plants and large fossil fuel power plants for several decades. With the advent of PC computer-based simulators, it has become feasible to build training simulators for smaller power plants including geothermal power plants. The development of the power plant simulator for Sudurnes Regional Heating Corporation (SRHC) started in 1998, and the first version was completed in 2000.

The power plant 5 (or in Icelandic; Orkuver 5, OV-5) simulator has mainly been used for training of SRHC plant operators. Some control and protection system studies concerning load shedding have included the use of the simulator. The simulator has been used at the United Nations University Geothermal Training Program in a course about simulation and simulators in geothermal projects.

2.2 Simulation and design

Simulation models with prepared teaching material have been used for teaching engineers various aspects of geothermal utilization at the United Nations University Geothermal Training Programme (UNU/GTP). Some of the engineering students have also developed their own models for design studies in their final projects. The students have developed models of geothermal greenhouse heating systems, house heating and power plants.

The UNU/GTP simulation models and teaching material cover all aspects of geothermal engineering. The students use the models for the following:

- Analysis of process design alternatives.
- Development and analysis of control strategies.
- Optimisation of operational strategies.
- Tuning and adjustment of control systems.
- The students develop their own models for their project work.

The UNU/GTP Geothermal Simulators consist of three specialized simulators:

- House Heating Simulator.
- District Heating Simulator.
- Geothermal Power Plant Simulator.

The simulators give valuable insight into the main factors that affect the operation of a modern geothermal power system. Emphasis is on training in the use of modern computer-based control systems, including SCADA systems, Programmable Logic Controllers, etc. A dynamic heating load model, based on weather forecasting, is connected to the simulated consumer network. It is possible to investigate the effect of insulation, air exchange, solar-heat and supply water temperature on heat loss and indoor temperature stability. Various factors, such as radiator sizes, insulation, window sizes and temperature controllers can be adjusted in the simulator model and their effects investigated.

Experience has shown that the use of simulators has proven to be a most effective and economical method in engineering teaching and training.

In schools where simulators have been taken into use, they quickly become the most popular and effective training tool.

By using simulators, trainees can experience a much wider spectrum of training than ever possible before. Students will thus be better and more efficiently trained than before.
Conventional static design methods have severe limitations since they do not take into account system dynamics. Substantial improvements in system design can be achieved by taking system dynamics into account in the design - by using a simulator.

Training scenarios included in the simulator are based on Geothermal Engineering teaching material used successfully for many years at the University of Iceland.

3 Control systems

3.1 Special requirements for control systems in geothermal projects

Geothermal projects often make special requirements on control systems (Gonsalves et al., 1988):

- Complex regulation of a largely custom-made process, often spread over a large geographic area.
- Communication system often based on many generations of equipment and protocols due to the evolution of the geothermal project during its lifetime.

- Varying and often non-standardized equipment sizes due to adaptation to well output.
- Due to the above variations, the automation software is most often custom-made and project specific.
- Due to the often remote location of geothermal projects, remote monitoring and control of the plant is often preferable.
- H_2S corrosion of electrical systems and electronics in high-temperature fields, places special requirements on air conditioning and control system design.

Older plants are often operating with many individual **analog systems**, each requiring custom support and training. Often data acquisition is limited to a few measurements. The need for excessive maintenance and many components becoming obsolete are often the main factors influencing the decision for an upgrade. The failure rate of old control system hardware increases which affects the plant reliability.

It's a myth that software does not age. Software ages quickly if it is not upgraded. The functions can only be guaranteed if the software is administered and updated regularly. If software is not regularly upgraded, there is a risk that service for the control system is no longer available. The engineering tools, manufacturer support and the service staff available will no longer be willing or able to service the control system with the old software. This could lead to prolonged unavailability of the plant in case of control system failure. It may therefore often turn out that the constant (often meaning annual or semi-annual) updating of the control system software is most economical. This is called keeping the system "evergreen" and is sometimes a requirement in a control system supplier maintenance contract. The reason is that the service work can be performed more efficiently if only the most recent software versions have to be dealt with.

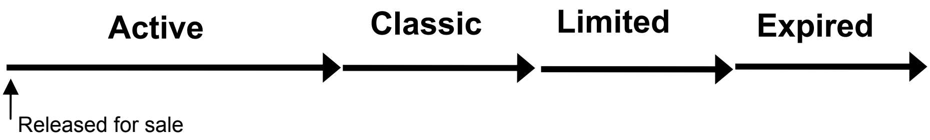
3.2 The life-cycle of a control system

The life-cycle of the control system is often shorter than that of the plant itself. For a geothermal power plant or district heating system with a lifetime longer than say 30 years, it may be expected that the control system will be renovated at least once during the life of the plant. If frequent modifications are being made to the control system, due to evolvement of the geothermal project, then the need for renovation of the control system will be more frequent. Several factors influence the need for control system renewal and the costs involved. The life-cycle cost of the control system is therefore not only dependent on the initial purchase price of the plant control system.

One aspect to consider is that the automation level (plant control system, PLCs) is much more stable (automation functions are seldom changed significantly) than the operator level (SCADA). This is because the IT technology that the SCADA is based on is subject to much shorter product cycles than the automation level. Every effort must therefore be made to make the frequent operator level upgrades as economical as possible, especially regarding the work intensive interface with the automation level (PLCs). Standardisation of the communication between the automation and operator level is very important in this respect. Effective migration strategies and tools for upgrading the operator level are another important aspect. A highly developed migration strategy for upgrades is a competitive edge that SCADA manufacturers with a strong market position often have.

3.2.1 The phases in a product life-cycle

A product life-cycle is often divided into the following phases or periods:



- **Active**: The product is marketed and developed further.
- **Classic**: The product is maintained and developed to a very limited degree.
- **Limited**: Service and support for the product is available, but may be hard to find. Price of spare parts increases sharply.
- **Expired**: Ad-hoc service. If part fails, no service may be available.

The active period in the automation level (PLCs etc) are most often about 10 - 15 years (in some cases 20 years) and in the operator level (HSI, SCADA) only 3-7 years. So it is obvious that there must be measures to protect the investment of the automation level. Standardized interfaces between automation and operation, like today's OPC, are suitable tools to interconnect different control systems (also vendor independent).

3.2.2 The importance of purchasing products of recent design

The Classic + Limited period is often roughly equal to the active period. For the automation level, the time from product release until the product has expired is therefore often about 20 – 30 years. If automation products of old design are purchased, then often they can be assumed to be nearing the classic period in their life-cycle, and the time until they expire and will require replacement will only be about 10 – 15 years.

3.2.3 The importance of purchasing products with strong market position

As happens in many market segments, there is an evolution in the direction of fewer makes and types of products, mainly due to the ever-increasing development cost for new products. Products with a small market share are therefore likely to have much shorter life-cycles than products that have a stronger market position. Products that are widespread often have strong third-party support that prolong the service life. The market position should therefore be looked into when choosing key control system components.

3.3 Planning for geothermal power plant control system upgrade

All upgrades of control systems should start with strategic planning, to ensure that the life-cycle cost of the plant is kept to a minimum and operational goals are met. Strategic planning starts with a thorough evaluation of the existing control system together with review of operational experience, then follows a study of the available options and their benefits vs. drawbacks.

Several benefits result from developing and implementing an overall strategy for the design and implementation of a new control system:

- Savings by selecting a standard digital platform. This usually means deciding on a control system from one or a few manufacturers. This reduces training and spare parts costs.
- Standardised Human-System-Interface (HSI). The HSI is key to the operators situational awareness and proper response to plant malfunctions. The use of many different types and often badly conceived HSI is one of the main sources of human factor deficiencies and operator mistakes in power plant operation.

In some instances, power plant modernizations are begun on an individual equipment or system basis, replacing the most problematic parts without consideration of an integrated, long-term view of the resulting plant control system architecture. Whether the modernization covers the whole plant at once or is implemented in several phases, strategic planning is needed as one of the initial steps in the modernization. The lack of strategic planning can result in:

- Older control system components are unable to communicate directly with current or future systems.
- Control system components may become prematurely obsolete due to lack of support or incompatibility with future control system additions.

3.3.1 Problems associated with upgrades to digital control systems

When implementing a digital control system, consideration must be given to potential for software **common-mode failures**. Redundant, software-based components are especially vulnerable to common-mode failures during software upgrades that can introduce the same failure to both parts of a redundant system. When planning an upgrade, due consideration must be given to this.

3.3.2 Human-System Interface Modernisation Plan

Planning for the impact of control system upgrade on the human-system interface is crucial (Hill et al., 2002). Power plant and control system modifications and upgrades are often piecemeal efforts implemented over a long time and without a firm plan for a resulting well-integrated and harmonized HSI. Each modification is designed on its own, often using different vendor equipment resulting in inconsistent human-system interface characteristics. History has shown that incoherent HSI modifications have been a significant source of human-factor related hazards in power plants. In addition, maintaining many types of HSI can become costly.

3.3.3 Human-System Interface design

When upgrading a control system and designing a new HSI, one of the first steps should be to check if the old, existing graphical HSI can be used as a basis for tools and base picture elements in the new HSI. Then the basic picture elements needed to create the process displays should be defined in detail. The dynamic behaviour of the picture elements and dialogues also need to be defined. The design of displays is often an iterative process between the HSI specialists and the customer.

It should be emphasized that the customer should be involved in the design of picture elements and other display conventions. This is to ensure that the design conforms to the existing plant HSI conventions and thus limits the amount of operator re-training required.

3.3.4 Naming conventions for systems, equipment and signals

When planning for major upgrades of a power plant, the opportunity is sometimes used to make a change to the naming system. To ensure that the naming conventions are applied consistently it is preferable that only one person or a group of persons should assign names for new signals and objects. It is important to make sure the naming system is completely defined and well understood by those assigning new names, before starting to use the new names.

3.3.5 Participation by plant or utility staff

The participation of plant staff in upgrade work has several advantages. They can bring to the project extensive knowledge of the existing plant and its operation. Direct participation in the upgrade project is perhaps the best form of training and education for operations and maintenance personnel. The problem is that often the staff have to perform all their normal duties in addition to the project work. This leads to conflicts with other tasks and the potential for delays or undesired technical solutions. The staff should therefore be relieved of most or all of their normal duties and preferably assigned to the upgrade project on a full-time basis.

3.4 Remote control

There is a trend to concentrate the operation of different power plants in centralized control rooms. This is of concern to power companies operating geothermal power plants, since in most cases they are operating more than one power plant and perhaps also a district heating system. This often leads to the problem of connecting the different power plant control systems to the Supervision Control and Data Acquisition System (SCADA) in the central control room.

Geothermal power plants are mostly located in remote and inconvenient areas. It is therefore of interest to install remote control and monitoring from a remote control centre, which is conveniently located. In recent years, remote monitoring and control in geothermal projects are being used to an increasing degree worldwide often leading to considerable savings in manpower. Closed Circuit TV (CCTV) is becoming popular for remote monitoring of the surroundings of the geothermal plant.

Remote control and reduced staffing on-site can affect plant availability. With reduced staffing on-site, it may take longer to get the required maintenance staff on-site in case of equipment failure. Plant outage time may therefore in some cases be longer. To compensate for this, redundant control equipment such as backup pumps that start automatically, may have to be installed in some cases. Modularisation of the process may also be applied to reduce the risk of one failure stopping the whole plant. The decision to monitor and control the plant remotely does thus usually have a significant effect on the design of new plants and their control system. In some cases, remote monitoring can facilitate diagnosis of a failure and thus reduce the time needed for repair. A careful consideration of all the factors affecting plant availability is needed when planning for remote control.

Remote control and monitoring of geothermal plants are quite often easy and relatively safe compared to other power plants such as fossil fuel because of the following:

1. Steam pressures and temperatures are relatively low and there is little threat of fire hazard compared to fossil fuel plants.
2. The generating units are relatively small. Adopting an air-cooled generator, instead of hydrogen cooling, eliminates the possibility of a hydrogen explosion.
3. Operation and maintenance of a geothermal power plant is easier than a fossil fuel thermal power plant, because it has no boiler; and plant systems are much simpler than a fossil fuel thermal power plant.
4. A geothermal power plant is usually operated at full load and its operation and monitoring is often simpler than in a fossil fuel plant.

It should be mentioned that high-temperature steam-fields are most often difficult to put under automatic control. This makes remote controlled load changes difficult and is often a major obstacle in the full automation and remote control of geothermal plants.

3.4.1 Control system configuration

The control system configuration of a modern power plant is based on computer hardware and software. (Kebede, 2002) Some key components are a SCADA system, communication equipment, programmable controllers, etc. (see Figure 2).

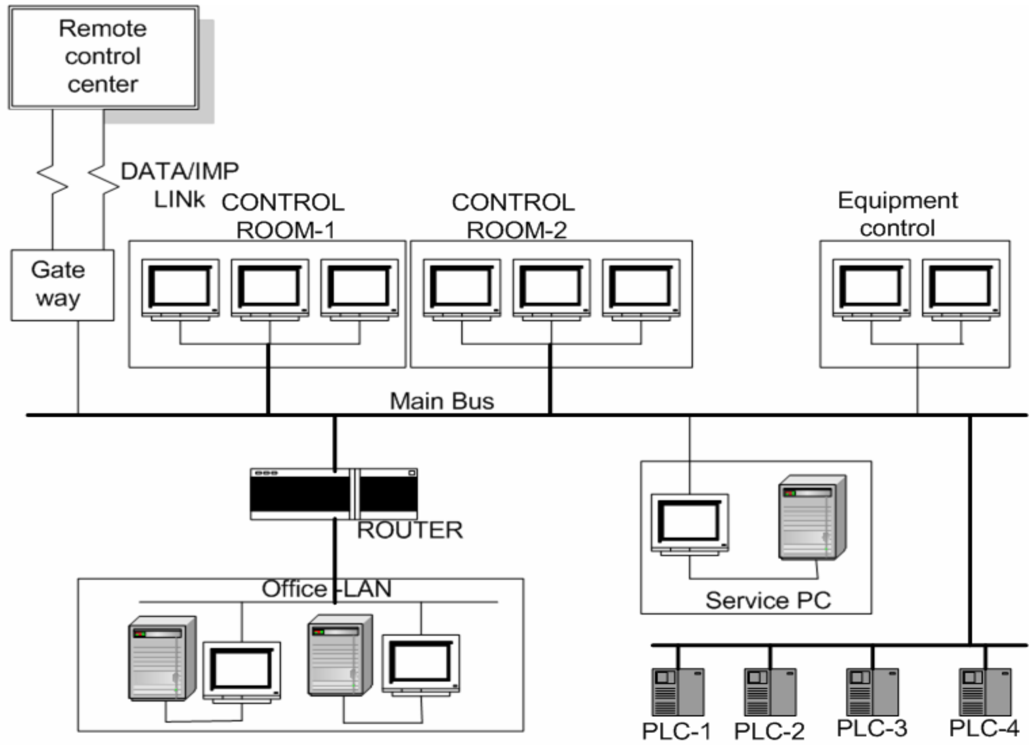


Figure 2: SCADA system hardware with PLC controllers

3.4.2 Hierarchical structuring of the control system

In geothermal power plants, the control system is often split into three different levels as remote control, local/station control, and backup/equipment control (see Figure 3). (Gunnarsson et al., 1992) The division into three control levels is primarily intended to increase the reliability of the control system. Most often the plant is controlled by a remote control system. The local/station control system is usually a copy of the remote control system except the location. The back-up is operative in case both the remote and the station system are not functional. Hence, the back-up is used in the emergency case and is simpler.

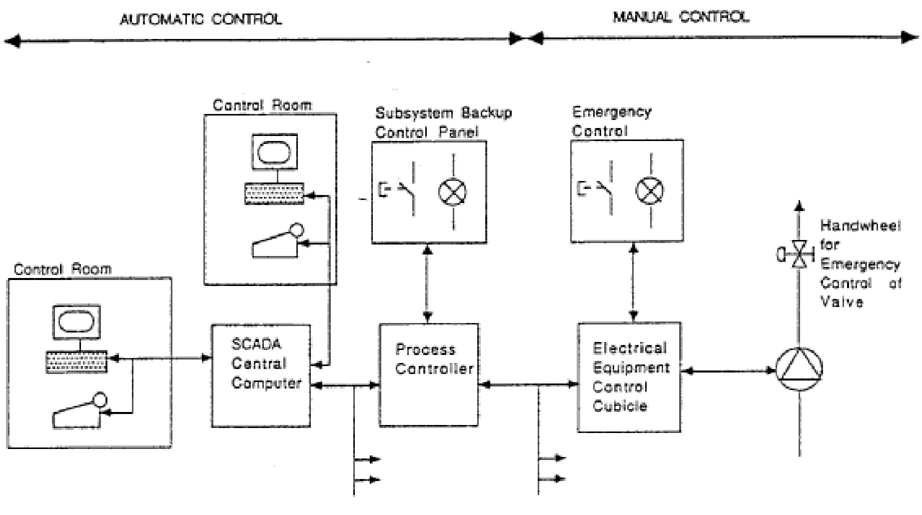


Figure 3: Control system hierarchy

3.4.3 Control system redundancy

Manual control is often difficult or cannot be applied for operation in case the main control system fails (Magnússon et al., 1989). A standby or redundancy control system is therefore important for reliable and uninterruptible operation of the plant. In geothermal power plants, control equipment for the steam and heat exchanger subsystem cannot be controlled manually as they are too fast. An automatic control system is therefore necessary.

The following diagram shows typical control redundancy for pumps. The standby pump starts automatically when one of the main pumps fail. The configuration of the I/O modules takes into account redundancies. As an example, see Figure 4. If one I/O module fails, only one pump will be non-operational. Common control system components, such as power supply and even PLC CPUs can also be made redundant for critical plant systems.

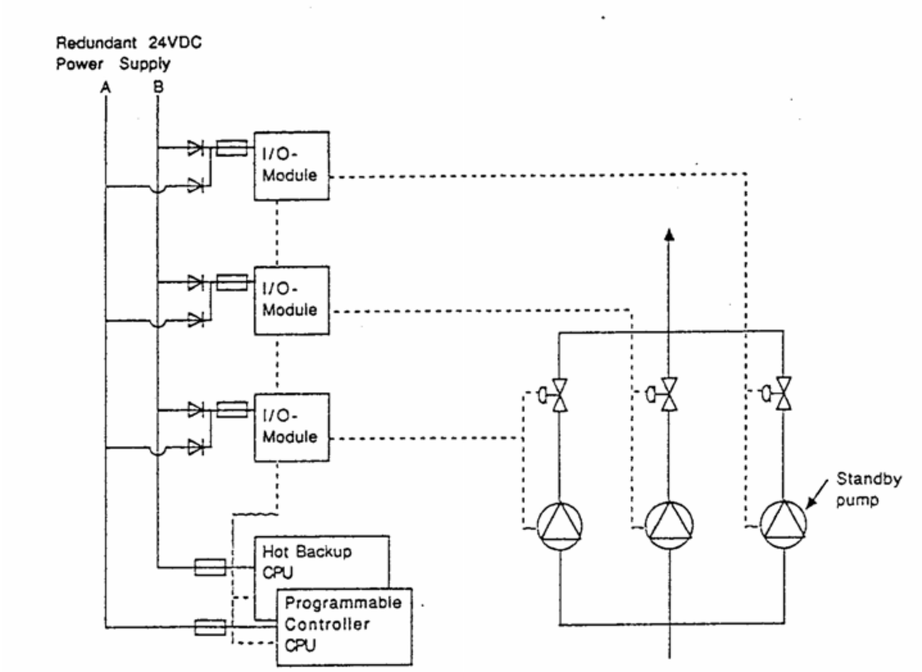


Figure 4: Control system redundancy

3.4.4 Hydrogen sulphide corrosion

Corrosion in a geothermal environment from hydrogen sulphide is a continuous problem (Hunt, 2000). Large outdoor exposed, heavy copper current-carrying items like bus bars, clamps and conductors are particularly vulnerable. Other items exposed to this type of problem are multi-layered flexible copper straps used for connections in outdoor HV disconnector switches and for bus bar flexible connections. Corrosion of cadmium-plated mild steel items, like nuts, bolts and washers will produce highly toxic residue.

Indoor electrical equipments, particularly electronic printed circuit boards with plug-in copper connections associated with control, instrumentation and protection equipment are particularly vulnerable to corrosion and failure.

The following methods help to overcome outdoor electrical equipment problems:

- Use of tinned and epoxy painted bulk copper.
- Use of corrosion resistant materials such as aluminium and stainless steel.
- Use of heat shrink material on exposed copper.
- Use of tinned copper wires.
- Varnishing and painting indoor items.

- Epoxy encapsulation of small components.
- Careful selection of paint systems and sealing gaskets.
- Mild steel galvanising and epoxy painting.

For indoor electrical equipment:

- Where H_2S levels are high, air conditioning systems should be fitted with special filters to remove H_2S, and special precautions should be taken to prevent unfiltered air from entering clean areas at all times. All sensitive equipment should be located in a positive pressurised and H_2S filtered room.
- Specification of H_2S rated instruments and connections.
- Specification of gold-plating on printed circuit board connections.
- Provision of control cubicles with anti-condensation heaters.

4 References

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