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INSTRUMENTATION APPRAISAL IN SINGLE AND DOUBLE FLASH POWER PLANTS

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ABSTRACT

Instrumentation used for the operation of power generation equipment in geothermal power plants need to be documented. This applies both to the design phase of the plant as well as when the plant is in operation. In this study the motivation behind instrument documentation is examined. The goal is to optimally revise and upgrade instrumentation and the associated documentation in accordance with the needs of the power plant. Finally, as a case study, the development of instrumentation needed in single and double flash geothermal power plants is examined.

1. INTRODUCTION

The necessary documents containing information used to control a geothermal power plant are issued at the point of commissioning and should be maintained throughout the lifecycle of the plant. Yet, this is not always the case. Measurements are usually taken for the use of operation and maintenance departments with the main concern being the availability and economic operation of the plant. However, several aspects of instrumentation systems change during the lifecycle of a plant as these systems need to be improved continuously. There should be a constant outlook for methods of enhancing the system´s capabilities, offering new and better solutions for process control. Some of these aspects include (Kalani, 2002):

- Standardization;
- Speed of response;
- Hardware variety;
- User interface;
- Compactness;
- Power requirement;
- Integrity.

As an example, modern instruments have self-checks and diagnostics capabilities. Through their use mean time between failures can be lowered and they can endure longer periods before needing repairs. Therefore, due to maintenance and upgrades, changes in the instrumentation systems are unavoidable.

This study reviews information concerning instrumentation from its initial design and through changes of the instrumentation systems throughout the plant's lifecycle. It seeks to provide recommendations on critical documents concerned with instrumentation and stresses the importance of keeping those documents actualized.

Design of control and instrumentation systems in a project produces several documents in the early stages of a conceptual study. These documents include information on (Kalani, 2002):

- Overall control and instrumentation. Functional requirements (e.g. control, monitoring, management, and engineering) are described, and then the system topology is explained.
- Process control system. Communication, operation, control, management and auxiliary facilities are indicated.
- Systems' interfaces. The method of interfacing various subsystems with the main control system is included.

Because some of these documents depend on the customs and practices of design offices, the scope of this report is limited to the following documents:

- Functional description;
- Piping and instrumentation diagram (P&ID);
- Instrumentation list.

These documents are listed by Kalani (2002) and are commonplace for power plants. Meier and Meier (2004) added another four documents to the list, covering specifications, logic and loop diagrams, installation details and location plans, but leaving the functional descriptions out.

The analysis proposed here is concerned mainly with geothermal power plants in liquid-dominated fields, but it is possible to extend the results to other kinds of plants with similar systems. In a liquid-dominated field, single flash technology is the first step in development. The problem is that a considerable amount of hot waste liquid is discharged from the separator; this hot liquid can be utilized by implementing a double flash system (DiPippo, 2008).

The study of instrumentation requirements in single and double flash power plants helps to define how to maintain the necessary documentation and achieve good availability. The process flow diagram is the starting point. It is developed in the first stages of design and only modified in response to major changes. It can be used to gain an understanding of the whole process and the inter-relationships of all the major equipment included.

The functional description puts into words all the behaviour expected from the power plant; it describes in detail all the possible scenarios in normal operation and emergencies. It is also the compilation of all procedures associated with the operation of equipment, including during start-up and shut-down of the plant. When there is a change in the system, this is the first document that needs to be modified and the guidelines to modify the others must come from it. It can include logical diagrams.

The piping and instrumentation diagram gives information about the control schemes utilized for the process and also safety systems and interlocks. It shows how pipes, equipment and instrumentation are connected. The instrumentation list includes all the instruments along with their descriptions, ranges, types, tag numbers and loop information.

In the following sections, control and instrumentation are presented, then the instrumentation documents are reviewed, and finally a case study of an ideal double flash power plant is presented.

2. CONTROL AND INSTRUMENTATION

At its most elemental level, the purpose of an instrumentation and control system is to provide a means of communicating process information (i.e. temperature, pressure, level, etc.) to an operator; it is also the means for modifying the process as needed to achieve a desired result (Whitt, 2004). Instruments are provided to monitor the key process variables during plant operation. They may be incorporated in automatic control loops or used for manual monitoring of the process operation. It is desirable to directly measure all process variables of interest; however, this is impractical, and some dependent variables that are easier to measure are often monitored in their place.

2.1 Reasons for utilizing instrumentation and control systems

The following aspects must be considered together and defined according to the site´s regulations (Towler and Sinnott, 2008):

- Safe plant operation;
- Production rate;
- Cost.

For safe plant operation, this means:

- Keeping variables within known safe operating limits;
- Detecting dangerous situations as they develop and providing alarms and automatic shutdown systems;
- Installing interlocks and alarms to prevent dangerous operating procedures.

In a typical plant, this is achieved by a combination of automatic controls, manual monitoring and online analysis.

2.2 Alarms, safety trips and interlocks

Alarms are used in a geothermal power plant for several reasons (Lipták, 2003):

- To guarantee the safety of operating personnel;
- To prevent the destruction of the capital investment;
- To minimize unit downtime;
- To comply with local, state, national and other regulations;
- To avoid civil suits resulting from property or personal damage external to the plant.

Where delay or lack of response by the operator is likely to lead to the rapid development of a hazardous situation, instruments should be fitted with a trip system which would activate automatically to avert a hazard.

The basic components of an automatic trip system are (Towler and Sinnott, 2008):

- A sensor to monitor the control variable;
- A link to transfer the signal to the actuator;
- An actuator to carry out the required action.

An example of this: in the steam collector, there is a valve connected to drainage in a local level control with electrodes acting as an alarm and as the set point.

Where it is necessary to follow a fixed sequence of operations, interlocks are included to prevent operators from departing from the required sequence. Care should be taken to test all of the interlocks in a plant's automation during commissioning or whenever changes are made to the plant's control and automation systems. An example of this: The turbine needs the low level alarm in the cooling tower and the low vacuum alarm cleared before opening inlet steam valves.

2.3 Improving instrumentation systems

There are several ways to improve instrumentation systems (Kalani, 2002):

- Use of redundancy;
- Use of de-rating for components;
- Use of self-checking (or periodic testing);
- Inclusion of field instruments in the analysis;
- Use of full automation and fool-proofing techniques;
- Use of preventive maintenance;
- Careful design of unit and system configuration.

Implementation of these principles will increase the cost of the system substantially, depending on how far each method is applied.

The use of redundancy in all systems is usually incorporated in the design. The 1oo2 (one out of two) redundancy is suitable for systems in which safety is more critical than loss of production, whereas 2oo2 (two out of two) is the reverse. A compromise is 2oo3 (two out of three), where both safety and production are improved.

To minimize operational and maintenance errors, full automation, fool-proofing techniques, and preventive/planned maintenance should be employed. De-rating and a well-designed system (units, configuration) will substantially reduce the effect of environmental stresses. Of course, a well-designed environment (control rooms) is always necessary. It is important to include field instruments (transmitters, valves) in the analysis because it is common knowledge that between 60 and 80 per cent of shutdowns is caused by the failure of these items.

The main advantage of 2oo3 systems is the inclusive superior availability. Availability depends on MTBF (mean time between failures) and mean time to repair (MTTR). In a 1oo1 or 1oo2 configuration, a single failure causes a shutdown and requires immediate maintenance attendance. In a well-designed 2oo3 safety system, however, a single failure can be tolerated for several days to several months, depending on the system´s robustness.

2.4 Typical instrumentation and control systems

When revising the instrumentation and control scheme, it is necessary to look at the guide rules used in the design, developed from the process flow sheet (Towler and Sinnott, 2008) and to:

- Identify loops needed for steady plant operation;
- Identify the key process variables that need to be controlled to achieve the specified process efficiency;
- Identify and include those additional control loops required for safe operation;
- Decide upon and show those ancillary instruments needed by operators for monitoring plant operations, for troubleshooting and plant development;
- Decide on the location of sample points;
- Decide on the alarms and interlocks needed.

Other criteria to utilize are the basic rules of process control:

- There can be only a single control valve on any given stream between unit operations;
- A level controller is needed wherever a vapour-liquid or liquid-liquid interface is maintained;
- Pressure control is more responsive when the pressure controller actuates a control valve on a vapour stream;
- Two operations cannot be controlled at different pressures unless there is a valve or other restriction (a compressor or a pump) between them;
- Temperature control is usually achieved by controlling the flow of a utility stream (such as steam or cooling water).

The most common control loops encountered in single and double flash power plants include: flow, level (Figure 1), pressure (Figure 2) and condenser with pressure control (Figure 3).

Flow is both a manipulated and a controlled variable, and has the fastest response of all the loops. Flow loops are always self-regulating. Ordinarily, a valve is selected to deliver the desired characteristic of flow (Shinskey, 1996).

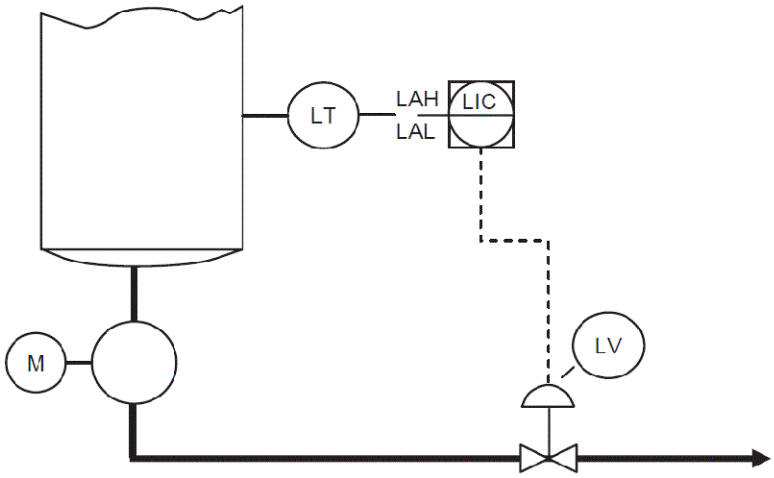

FIGURE 1: Level control (Towler and Sinnott, 2008); LT: Level transmitter; LAH: Alarm level high; LAL: Alarm level low; LIC: Level controller and indicator; M: Motor; LV: Level valve

Liquid level is the integral of the difference between the flows into and out of a vessel (Shinskey, 1996). In Figure 1 the level controller (LIC) acts on the outlet valve (LV) to maintain the desired level.

Level is measured as a distance or as a difference in pressure by the transmitter (LT) and the output of the controller is a position command to the valve, the final acting element.

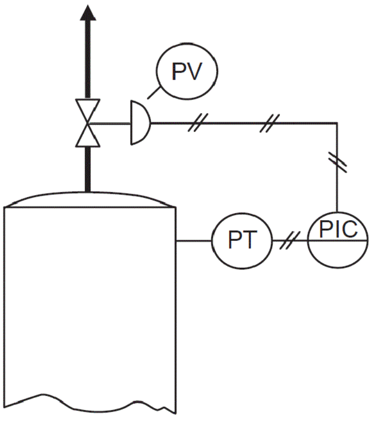

FIGURE 2: Pressure control (Towler and Sinnott, 2008); PV: Pressure valve; PIC: Pressure controller and indicator; PT: Pressure transmitter

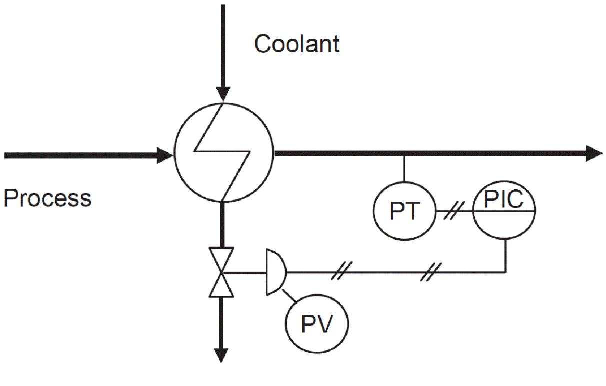

FIGURE 3: Condenser pressure control on coolant flow (Towler and Sinnott, 2008) PV: Pressure valve; PT: Pressure transmitter; PIC: Pressure controller and indicator

Pressure has two different behaviours in geothermal: a liquid-pressure loop behaves linearly and has a fast response; a vapour-pressure loop is lag-dominant (like liquid-level) but is self-regulating as rising pressure tends to both increase outflow and decrease inflow (Shinskey, 1996).

In Figure 2 the pressure controller (PIC) acts on the outlet valve (PV) to control pressure. If the fluid is leaving the process, the valve is called a pressure relief valve. Pressure is measured directly by the transmitter (PT) and the output is a position command to the output valve (PV).

In Figure 3, the pressure controller (PIC) acts on the outlet valve (PV) to control the flow of the coolant. This method is used to control the vacuum pressure in the condenser. Vacuum pressure is measured directly by the transmitter (PT) and the output is a position command to the output valve (PV).

3. INSTRUMENTATION DOCUMENTS

3.1 Process flow diagram (PFD)

According to Towler and Sinnott (2008), the process flow diagram shows the arrangement of the major pieces of equipment and their interconnection. It is more a description of the nature of the process than a design document.

The PFD is used by specialist design groups as the basis for their designs. These include piping, instrumentation and plant layout. During plant start-up and subsequent operation, the flow sheet forms a basis for comparison of operating performance with design. It contains the flow rates, temperature, enthalpy and pressure of all streams in the process.

The PFD must show equipment identification, and include a list of the principal assumptions used in the calculations. It is normally reviewed before the release to detail design, to ensure that there is enough information to support development of the piping and instrumentation diagrams (P&IDs) (Meier and Meier, 2004).

The utility connections required on each piece of equipment should be shown and labelled. Utility requirements should be tabulated in the flow sheet.

The process flow diagram completes the initial documentation of the process technology and automation tasks. As such, it becomes necessary to define in detail the measuring and control points. This is done by entering the points on the process flow diagram, and the process flow diagram becomes the P&ID (Bischoff et al., 1997).

3.2 Functional description

Sometimes, call performance specification or control narrative contains the requirements from the user´s viewpoint, including all parameter conditions, and a concrete solution approach. This specification defines WHAT is to be solved and the PURPOSE of the solution and describes the implementation requirements. The performance specification also defines HOW and WITH WHAT the requirements are to be implemented (Bischoff et al., 1997). Functional description starts with an evaluation of the process flow diagram, including the corresponding process description.

The first thing to do is to put together preliminary control sequences in which only the major control functions are shown (Whitt, 2004); second is to differentiate discrete and continuous control functions – possibly producing other documents, like the sequential function chart (SFC) and the continuous function chart (CFC) shown by Whitt (2004) – to finally get the functional description (control narrative), which is a text-based description of the control system.

An example: Flasher level control
A flasher inlet consists of a pipe with saturated geothermal water at 160°C with a valve regulated to lower the pressure to 0.6 bar. The water level inside the flasher must be maintained at 1.5 m from the bottom, with a tolerance of 0.5 m. The residual water is taken out with a pump. To control the level, a variable frequency drive (VFD) is connected to the motor and the discharge is controlled according to the level measured with a transmitter. In case of motor failure or when the level goes above 2.0 m, a control valve opens automatically. This valve should be completely closed below 1.75 m.

3.3 Piping and instrumentation diagram (P&ID)

The PFD is a purely conceptual document. It only has the minimum information relating to the specifics of the piping or instrumentation of a system (Whitt, 2004). The P&ID shows the engineering details of the equipment, instruments, piping, valves and fittings and their arrangement. It is often called the Engineer Flow sheet or Engineering Line Diagram.

P&IDs are produced and revised over many years by different people to reflect process improvements and additions, as well as changing control technology (Meier and Meier, 2004). Even symbolism may change, for example, the original publication standard ANSI/ISA-5.1-2009 is used worldwide but only as a reference for instrument symbolism in site standards.

The information included also depends on the design office customs and practices and could have very detailed information on the following items (Towler and Sinnott, 2008):

- Equipment;
- Pipes;
- Valves;
- Ancillary fittings;
- Pumps;
- Control loops.

The P&ID diagram should resemble the process flow sheet, but the process information is not shown. Each item shown on the P&ID is given a unique identification number called a P&ID tag, which allows the item to be tracked throughout the design (Whitt, 2004).

According to Meier and Meier (2004), P&IDs are developed in steps. First the major equipment is drawn; afterwards all the instrumentation and control equipment is added, often requiring additional space.
Also, P&IDs are controlled documents: control means that there should be verification checking or some other quality assurance procedure to show that P&IDs carry the definitive information from which many design entities draw their work.

An example, using the flasher level control described in the previous section, is shown in Figure 4.

3.4 Instrumentation list

An instrumentation list contains the final information about the tag, the purpose of the instrument, the type, the range and any other important information discussed on site. It should be simple and has to be kept actualized at all times.

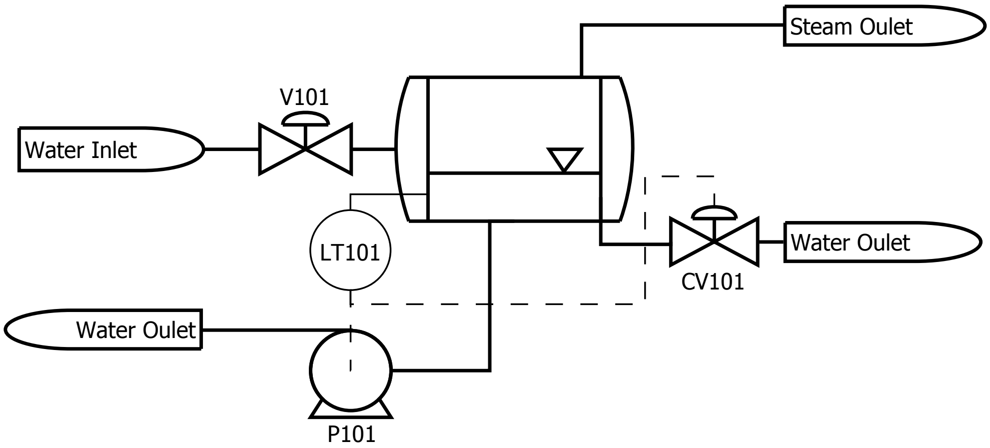

FIGURE 4: P&ID for flasher level control

Medida (2008) proposed that the content of the instrumentation list have an instrument index list with all the associated documentation, such as loop drawing number, datasheets, installation details and P&ID. The other parts of the instrumentation list should describe the role of the device, tag number, specification and details of the model type and number. According to Meier and Meier (2004), the information developed and maintained for process control could reside in a computer and in a more flexible form called an instrument database. The instrument list and the instrument index are simply subsets of the instrument information available in the database. Since most instrument signals are fed to a computer system, the instrument list and the inputs and outputs list (I/O list) may be combined into a single database to reduce data-entry overlap (Whitt, 2004).

An example of an instrumentation list using the flasher level control example is shown in Table 1.

TABLE 1: Instrumentation list for a flasher level control

Tag	Name	Description	Range	Type	Signal	Additional information
V101	Valve 101	Flasher inlet valve	-	-	-	-
CV101	Control valve 101	Emergency level control valve	0-100 %	4-20 mA HART	AO-101 AI-101	Pneumatic valve with position transmitter.
LT101	Level transmitter 101	Flasher level transmitter	0-2.5 m	4-20 mA HART	AI-102	Differential pressure level transmitter.
P101	Pump 101	Reinjection pump	0-1800 rpm	4-20 mA	AO-102	Connected to a VFD.

A general rule of thumb is that if something has to be purchased, mounted, wired or tubed, then it should appear in the instrument list (Meier and Meier, 2004).

4. SINGLE AND DOUBLE FLASH POWER PLANTS

According to DiPippo (2008), single flash systems indicate that the fluid has undergone a process from a pressurized liquid to a mixture of liquid and vapour, as a result of lowering the fluid pressure below the saturation pressure corresponding to the fluid temperature. In double flash, the design differs in that a flasher has been added so there is a low pressure steam line from it to the turbine, in addition to the high pressure line from the separator.

The flash process may occur in a number of places:

- In the reservoir as the fluid flows through the permeable formation with an accompanying pressure drop;
- In the production well anywhere from the entry point to the wellhead as a result of the loss of pressure due to friction and the gravity head;
- In the inlet to the cyclone separator as a result of a throttling process induced by a control valve or an orifice plate. In the flasher this is what happens to the high pressure separated water.

It is often the case in a newly developed field that flashing occurs in the wellbore initially but, with time, as the field undergoes exploitation and the reservoir pressure declines, the flash point may move down the well and even enter the formation.

While the actual location of the flash point can be important in the operation of a power plant, from the point of view of understanding the thermodynamics of the energy conversion process it is irrelevant. For the double flash power plant in Figure 5, it is assumed that the fluid starts off as a compressed liquid somewhere in the reservoir, that it experiences a flashing process somewhere, that the two-phases are separated, and that the steam is then used to drive a turbine which in turn drives the electric generator.

The turbine design shown in Figure 5 has two separate turbines, one for the high-pressure steam and one for the low-pressure steam. Other designs are possible, for example dual-admission, and single or double flow (for larger power ratings).

The processes undergone by the fluid are best viewed in a thermodynamic state diagram in which the fluid temperature is plotted on the ordinate and the fluid specific entropy is plotted on the abscissa. Figure 6 shows the diagram for a double flash plant.

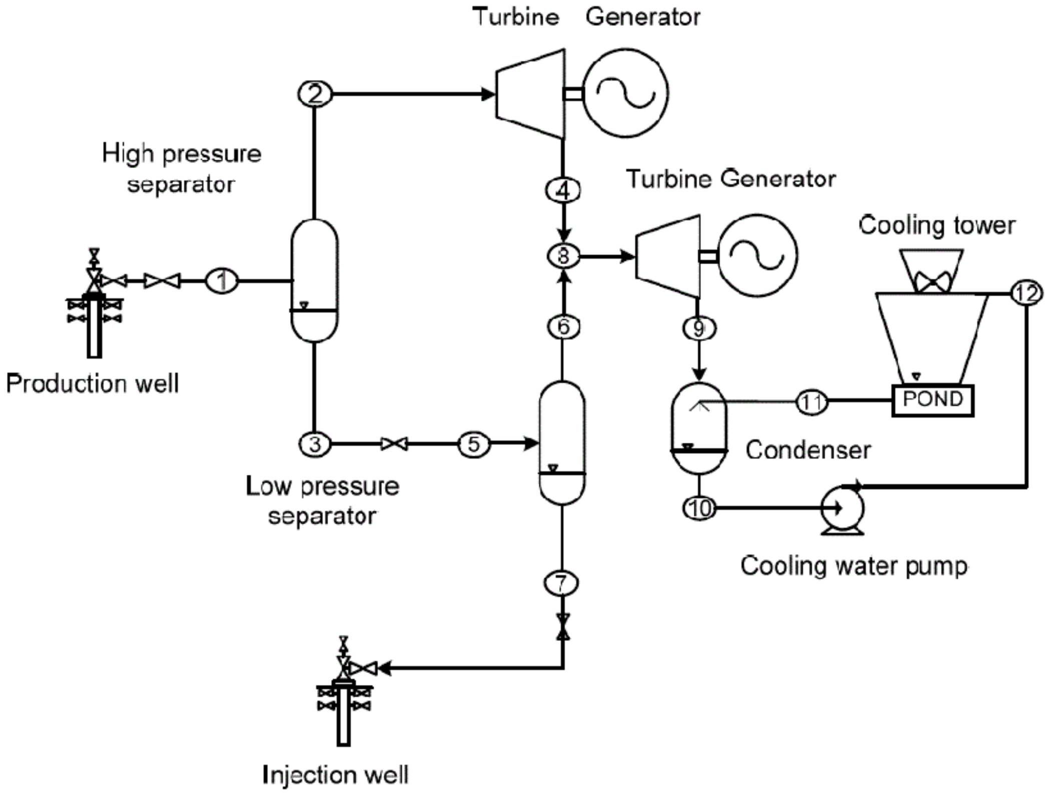

FIGURE 5: Double flash power plant (Bandoro, 2009)

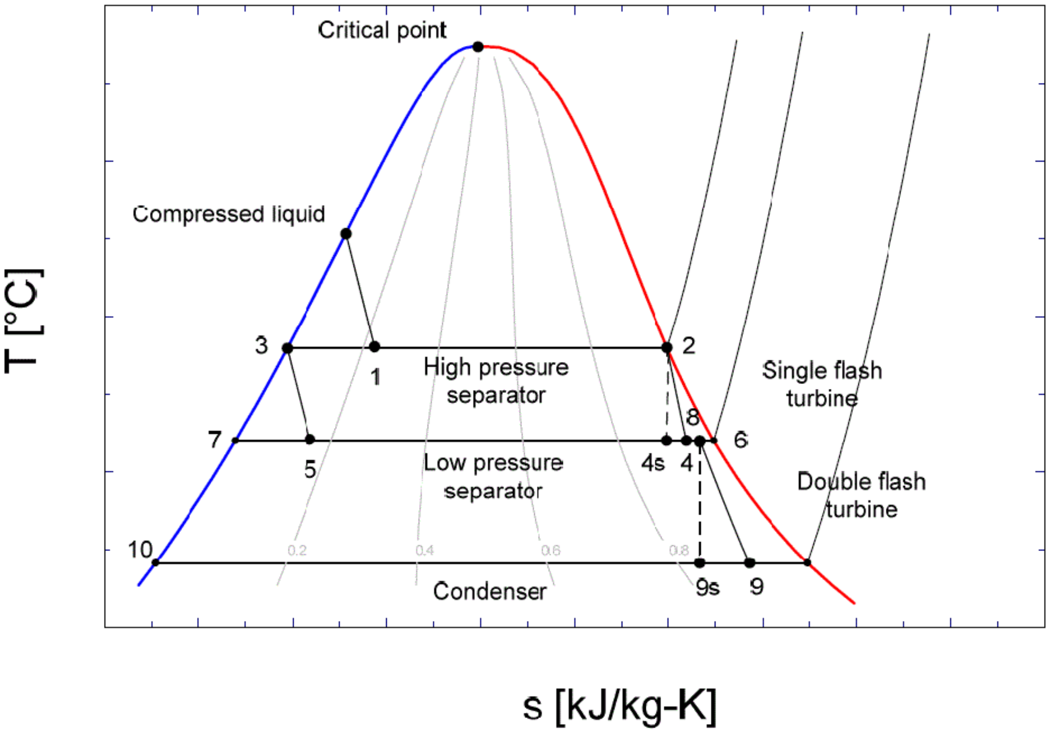

FIGURE 6: T-S diagram of a double flash power plant (Bandoro, 2009)

From the reservoir (state 0, not shown) to the separator (state 1), this is considered an isenthalpic process, then the separator takes the vapour to the turbine (state 2) and water to the flasher in the double flash process or for reinjection in the single flash process (state 3).

The high pressure turbine outlet (state 4) is mixed with flashed steam (state 6).

After it has lost pressure (state 5), the water is separated (state 7) and goes to reinjection (only in double flash). The mixed low pressure steam (state 8) goes to the low pressure turbine (state 9).

The steam coming out of the turbine is condensed quickly to create vacuum (state 10) with the cold water coming from the cooling tower (state 11).

The process that has thus been described has several parameters that need to be monitored and controlled. The following discussion addresses some of the parameters that need to be measured in auxiliary equipment of the process.

4.1 Production wells

The parameters of interest here are enthalpy, mass and steam fraction. The following assumptions are made:

- The liquid at the bottom of separators/flashers is saturated, provided the water level can be found;
- The rise of the steam/water mixture in the well is isenthalpic;
- Non condensable gases are neglected for the analysis, but are measured in the well in the production test or in the steam collector (turbine inlet), so they are taken into account in the turbine efficiency.

Temperature logs and production tests would give the mass flow and enthalpy at the well's bottom needed for calculations. These measurements extend over years, and it is assumed that the well behaves in a similar way between production tests. This is normally the case as any deviation could indicate problems in the reservoir or in the borehole.

For control purposes, pressure and temperature need to be measured at the well head so that the two-phase mixture losses can be monitored (Figure 6, state 1).

4.2 Separator

To get the steam fraction, it is more convenient to measure steam and water separately; this is normally done using differential pressures. Also, in the separation process the losses begin to become important so it is necessary to measure temperature and pressure again. Saturated steam and water immediately give the enthalpy in those points (Figure 6, states 2 and 3). State 3 is the same as state 7 in the single flash turbine.

The assumption of constant enthalpy from the reservoir to the separator could be monitored here. Because of the two-phase mixture in the separator, the level should be measured and controlled.

4.3 Turbine

Provided that there is more than one well contributing to the turbine, a steam collector is needed; for the purposes of this analysis, the following assumptions about the turbine are made:

- The steam gathering system extends from each well to a collector which has pressure and level measurements for protection and control;
- A demister that is connected after the steam collector to guarantee the quality at the turbine inlet also has a level measurement installed for control;
- There is only one turbine; as is normally the case, even in the double flash process, low pressure steam enters the later stages at a set pressure and mixing takes place inside the turbine. Figure 5 shows them separately only to clarify the process.

All losses of the gathering system are taken into account, so all of the parameters are measured close to the turbine: the total mass flow, pressure and temperature (Figure 6, state 2). These measurements are used for monitoring and controlling the process, but also for comparison with the power outlet of the turbine (measured as power in the generator´s terminals). Enthalpy and entropy are calculated at state 2.

Measurements from the flasher (in the double flash process) and from the condenser are also needed to calculate the enthalpy and the steam fraction of states 4, 8 and 9. State 8 is the low pressure inlet for the double flash turbine. State 4 is the same as state 9 for a single flash turbine.

4.4 Condenser

For the condenser, the following assumptions are made:

- There is a cooling tower that evaporates a balancing mass and lowers the temperature of the condenser water so that the pressure in state 9 can be maintained;
- This cooling tower has level measurement for control because of the interface between water and air.

Controlling the condenser is difficult because of the variability associated with the condensing medium (Shinskey, 1996). The pressure and temperature at the condenser inlet are measured (Figure 6, state 9). Pressure is measured because there is a pressure control on coolant flow (as noted in section 4.4 and indicated in Figure 4). The temperature at the condenser outlet is measured to monitor the efficiency of the condenser and the cooling tower behaviour (Figure 6, state 10). Because of the two-phase mixture in the condenser, level measurement is required for control.

4.5 Flasher

For the flasher, the following assumption is made:

- The pressure drop and separation occur at the same place (Figure 5, points 3 and 5 are the same).

As in the steam collector, water enthalpy and mass flow at the entrance need to be calculated; but flow is measured at the two outlets (Figure 6, states 6 and 7) for control, as follows:

- Mass flow, pressure and temperature are measured in the flasher steam outlet (Figure 6, state 6), so it is possible to calculate enthalpy and entropy before mixing occurs in the turbine's low pressure entrance;
- Pressure is measured for a protection control loop in state 6 and a level measurement is needed because of the two-phase mixture in the flasher;
- Water flow is measured in the water outlet of the flasher for enthalpy, mass flow calculations and reinjection control (which is normally a pump station).

5. INSTRUMENTATION IN SINGLE AND DOUBLE FLASH POWER PLANTS

In the previous section, an example of a double flash power plant with an ideal PFD was presented in Figure 5, and generalized functional descriptions in Figure 6. Measurement requirements of the proposed equipment were then addressed. In this section, the previous information is used to construct a P&ID and an instrumentation list.

5.1 Loops needed for steady plant operation

The following measurements for control loops were identified for a double flash power plant (Figure 7):

Level in separator: L1
Level in flasher: L3
Flow in turbine high pressure inlet: F5
Flow in turbine low pressure inlet: F6
Pressure in condenser: P7
Level in condenser: L7

5.2 Key process variables to achieve specified efficiency

In geothermal power generation, achieving specified turbine efficiency means close monitoring of all parameters described in 4.3, namely flow, pressure and temperature in both high pressure (F5, P5 and T5) and low pressure inlets (F6, P6 and T6) as well as condenser pressure (P7).

5.3 Additional control loops required for safe operation

The following measurements for control loops were identified for a double flash power plant for safety reasons (Figure 7):

Pressure in high pressure steam collector: P2
Level in high pressure steam collector: L2
Pressure in flasher: P3
Level in demister: L5
Level in cooling tower: L8

5.4 Monitoring points for operation, troubleshooting and plant development

The following measurements were taken for monitoring plant operations, troubleshooting and for plant development (Figure 7):

Pressure and temperature in separator: P1, T1
Flow in collector inlet: F2
Flow in flasher inlet: F3
Flow in flasher water outlet: F4
Temperature in condenser: T7
Temperature in condenser outlet: T8
Pressure in reinjection pump discharge: P4
Pressure in circulation pump discharge: P8

The two last measurements are examples of instrumentation added for troubleshooting (pump start confirmation). Also, there is another kind of measurement that is not part of the process: equipment instrumentation added by the designer for the health of the equipment, such as resistance temperature detectors (RTD) in motors.

5.5 Location of measurement points

The preferred location of measurement points can change during later stages of design (actual purchase of equipment). This can be demonstrated by an example: in the turbine, because of losses or process conditions, measurements are wanted as close as possible to the turbine. For example, the pressure value in P5 would be different before and after the control valve FV5, shown in Figure 7.

5.6 Decision on alarms and interlocks

This is also relevant for the later stages of design (purchasing), but the example of a circulation water pump that will not start if the level in the cooling tower (L8) is below a minimum can be used.

5.7 Proposed piping and instrumentation diagram for single and double flash power plant

Figure 7 shows the proposed P&ID after following the design information of the ideal double flash power plant, from the production well to the reinjection areas of the field.

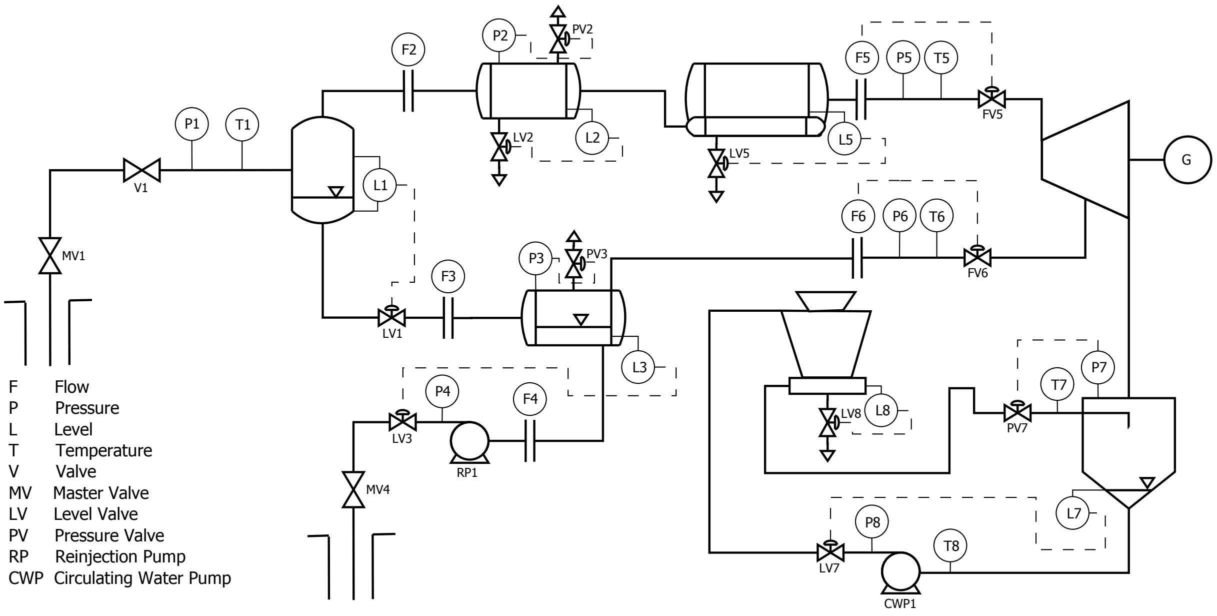

FIGURE 7: The proposed P&ID for single and double flash power plants

5.8 Proposed instrumentation list for single and double flash power plants

Using the P&ID of Figure 7, the necessary data is obtained for the instrumentation list shown in Table 2.

6. CONCLUSIONS

Three instrumentation documents were reviewed in this study (four if the PFD is counted): the functional description, P&ID and the instrumentation list, to discuss which information should be included and the importance of keeping these documents for operation and maintenance departments.

Necessary instrumentation for monitoring and controlling the process, and also for safety reasons, has been proposed for single and double flash geothermal power plants. Figure 7 shows the diagram proposed and the instrumentation list is found in Table 2.

The temperature-entropy diagram was used to apply the criteria to an ideal case. Results can be deepened for a more specific approach.

Emphasis has been made to base the criteria on the rules for P&ID design, because it is the best known document for control and instrumentation, the common practice observed in plants.

This study is not an extensive list regarding design but a recommendation for revision of existing instrumentation in a plant regarding WHAT needs to be measured and WHY.

Auxiliary and safety equipment have been kept to a minimum for the sake of simplicity and scope. In the advanced design phase, this should be revised as needed as it becomes clear upon review of purchased equipment needs, thus, making the instrumentation documents a part of the plant's lifecycle.

TABLE 2: Instrumentation list for single and double flash power plants

Tag	**Name**	**Description**	**State (Figure 6)**	**Purpose**	**Location**
MV1	Master valve 1	Wellhead valve	-	-	Production well
V1	Valve 1	-	-	-	
P1	Pressure 1	Separator inlet pressure	1	Monitoring	Separator
L1	Level 1	Separator water level	3	Control	
LV1	Level valve 1	Separator level control valve	-	Control	
T1	Temperature 1	Separator inlet temperature	1	Monitoring	
F2	Flow 2	Collector inlet flow	2	Monitoring	Collector
P2	Pressure 2	Collector pressure	2	Safety	
PV2	Pressure valve 2	Collector pressure control valve	-	Safety	
L2	Level 2	Collector level	-	Safety	
LV2	Level valve 2	Collector level control valve	-	Safety	
F3	Flow 3	Flasher inlet flow	3	Monitoring	Flasher
P3	Pressure 3	Flasher pressure	6	Safety	
PV3	Pressure valve 3	Flasher pressure control valve	-	Safety	
L3	Level 3	Flasher level	-	Safety	
LV3	Level valve 3	Flasher level control valve	-	Safety	
F4	Flow 4	Flasher outlet water flow	7	Monitoring	Reinjection well
P4	Pressure 4	Reinjection pressure	-	Monitoring	
MV4	Master valve 4	Wellhead valve	-	-	
RP1	Reinjection pump 1	Reinjection pump	-	-	
L5	Level 5	Demister level	-	Safety	Demister
LV5	Level valve 5	Demister level control valve	-	Safety	
F5	Flow 5	Turbine high pressure inlet flow	2	Control	Turbine high-pressure inlet
FV5	Flow valve 5	Turbine high-pressure flow control valve	-	Control	
P5	Pressure 5	Turbine high-pressure inlet	2	Monitoring	
T5	Temperature 5	Turbine high-pressure inlet temperature	2	Monitoring	
F6	Flow 6	Turbine low pressure inlet flow	6	Control	Turbine low pressure inlet
FV6	Flow valve 6	Turbine low pressure flow control valve	-	Control	
P6	Pressure 6	Turbine low pressure inlet	6	Monitoring	
T6	Temperature 6	Turbine low pressure inlet temperature	6	Monitoring	
P7	Pressure 7	Condenser pressure	9	Control	Condenser
PV7	Pressure valve 7	Condenser pressure control valve	9	Control	
L7	Level 7	Condenser water level	-	Safety	
LV7	Level valve 7	Condenser level control valve	-	Safety	
T7	Temperature 7	Condenser temperature	9	Monitoring	
P8	Pressure 8	Circulating water pressure	-	Monitoring	Cooling tower
L8	Level 8	Cooling tower level	-	Safety	
LV8	Level valve 8	Cooling tower level control valve	-	Safety	
T8	Temperature 8	Cooling tower inlet temperature	10	Monitoring	
CWP1	Circulating water pump 1	Circulating water pump	-	-	

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NOMENCLATURE

1oo1 = One out of one. Loop consisting in one analogue transmitter and an analogue controller.
1oo2 = One out of two. Two transmitters in parallel; the failure of one determines the loss of control.
2oo2 = Two out of two. Two transmitters in parallel; the loss of control should be determined by the failure of both.
2oo3 = Two out of three. Three transmitters in parallel; current value indicated by two of them is assumed as correct and representative of the process conditions. Concurrency means that they differ by no more than X%.
ANSI = American National Standards Institute
CFC = Continuous function chart
CV = Control valve
CWP = Circulating water pump
FV = Flow valve
HART = Highway Addressable Remote Transducer Protocol. The most popular industrial automation protocol; It can communicate over legacy 4 – 20 mA analogue instrumentation wiring, sharing the pair of wires used by the older system.
ISA = Instrumentation, Systems, and Automation Society
I/O list = Inputs and outputs list
LAH = Level alarm high
LAL = Level alarm low
LIC = Level indicator and control
LP = Low pressure
LT = Level transmitter
LV = Level valve
M = Motor
MV = Master valve
P&ID = Piping and instrumentation diagram
PFD = Process flow diagram
PIC = Pressure indicator and control
PT = Pressure transmitter
PV = Pressure valve
RTD = Resistance temperature detector
RP = Reinjection pump

SFC = Sequential function chart
V = Valve. Normal valve manually operated
VFD = Variable frequency drive. A system for controlling the rotational speed of an alternating current electric motor by controlling the frequency of the electrical power supplied.

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