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MAINTENANCE SYSTEMS OF AHUACHAPAN POWER PLANT, EL SALVADOR AND SVARTSENGI POWER PLANT, ICELAND: COMPARISON AND OPTIMIZATION PROPOSAL FOR THE AHUACHAPAN MAINTENANCE SYSTEM

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ABSTRACT

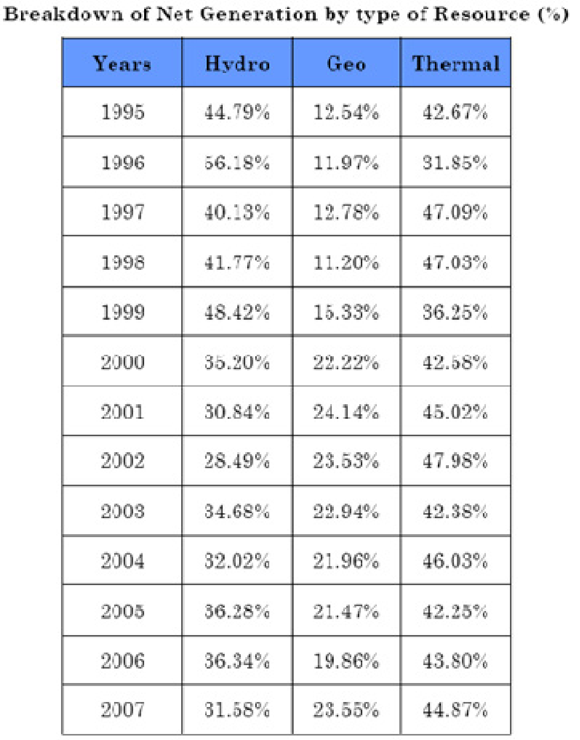
Maintenance processes of Svartsengi power plant (Iceland) and Ahuachapan power plant (El Salvador) are compared with the aim of proposing alternative practices in order to reduce the time required for maintenance in Ahuachapan power plant (El Salvador). In Svartsengi, much of the mechanical equipment is controlled by a predictive system and, thus, not considered part of the overhaul process, while in Ahuachapan all the mechanical equipment is overhauled. This difference between the two systems means that less time is needed for an overhaul in Svartsengi power plant. The activity which gives the greatest time difference is that of cleaning parts of the turbine; in Svartsengi, this is done by an external company which uses a water blasting procedure that reduces by half the time required in Ahuachapan, where the procedure is done manually. According to the comparison to reduce the time needed for overhauls in Ahuachapan the following activities are most important: evaluate the possibility of using the Svartsengi method for cleaning the turbine, and installing equipment available to prevent the risk of solid particles damaging bearings and servomotors and hence eliminating oil flushing. Thus, it would be possible to reduce the time required for an overhaul in Ahuachapan by five days.

1. INTRODUCTION

With regard to the supply of electrical generation, the leading position of the market in El Salvador is taken by thermal generation, comprising almost half of the total energy generated. Hydro generation takes second place, and finally geothermal comes in third place.

Maximum demand in the wholesale electricity market in 2007 was 906 MW, showing a growth of 2.8% from 2006, when it was 881 MW. In the wholesale electricity market, the energy demand in 2007 was 5,262 GWh, with a growth of 3.0% from the 5,109 GWh reported in 2006. The contracts market accounted for 55.2% and the spot market (MRS) for 44.8%. The breakdown in demand in the contracts market and the spot market in 2006 and 2007 shows variations experienced in each market. Figure 1 shows the distribution of energy production and an increase in thermal generation at a time of reduced geothermal production for reasons of maintenance. During this period, the production of the hydroelectric plants must be maintained at its normal capacity (SIGET, 2007).

Figure 2 shows the prices according to the UT statistical report (UT, 2007); prices vary according to the source of production; low costs are obtained from hydroelectric production and are expected soon from geothermal production. Thermal production is associated with higher costs since it depends on the price of fuel. According to the present study, the best way to reduce the costs of electricity is to reduce the amount of thermally produced electricity and the amount of time needed for maintenance in geothermal plants and. With regards to the maintenance, the optimal generation is stopped and this reduces income. For the study, information on Svartsengi plant was obtained in order to make an analysis of procedures, personnel, tools used etc, and to find which improvements in maintenance procedures could be implemented in Ahuachapan power plant.



Breakdown of Net Generation by type of Resource (%)

Years	Hydro	Geo	Thermal
1995	44.79%	12.54%	42.67%
1996	56.18%	11.97%	31.85%
1997	40.13%	12.78%	47.09%
1998	41.77%	11.20%	47.03%
1999	48.42%	15.33%	36.25%
2000	35.20%	22.22%	42.58%
2001	30.84%	24.14%	45.02%
2002	28.49%	23.53%	47.98%
2003	34.68%	22.94%	42.38%
2004	32.02%	21.96%	46.03%
2005	36.28%	21.47%	42.25%
2006	36.34%	19.86%	43.80%
2007	31.58%	23.55%	44.87%

FIGURE 1: Generation by type of resource (%)

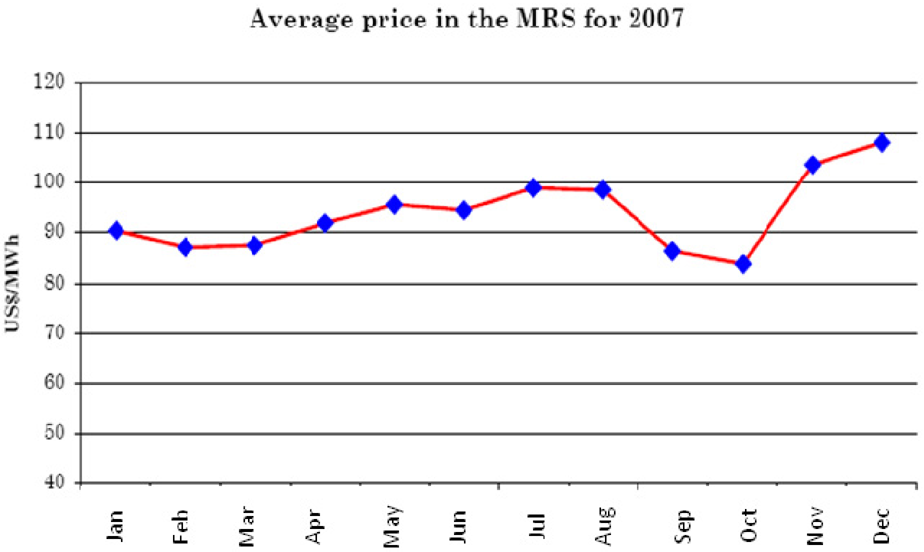


FIGURE 2: Average price of electricity in El Salvador

2. DESCRIPTION OF THE AHUACHAPAN POWER PLANT

2.1 General information

Ahuachapán power plant is located 103 km west of the capital city of San Salvador, 3 km east of Ahuachapán City (Figure 3). The operation of the power plant started with the installation of a Mitsubishi unit (30 MWe single-flash condensing type) in 1975 and a few months later in 1976 an additional, identical Mitsubishi 30 MWe unit was added. In 1981 a new Fuji 35 MWe unit 3 (double-flash type) came on line using separated brine to produce low-pressure steam, bringing the total installed capacity to 95 MWe. The reservoir pressure in the period from 1975 to 1983 was good. After that, the pressure began to drop with this situation considered to be due to overproduction of the reservoir. Since 1983, the plant has run the three units, although not to their full capacity.

FIGURE 3: Map of El Salvador

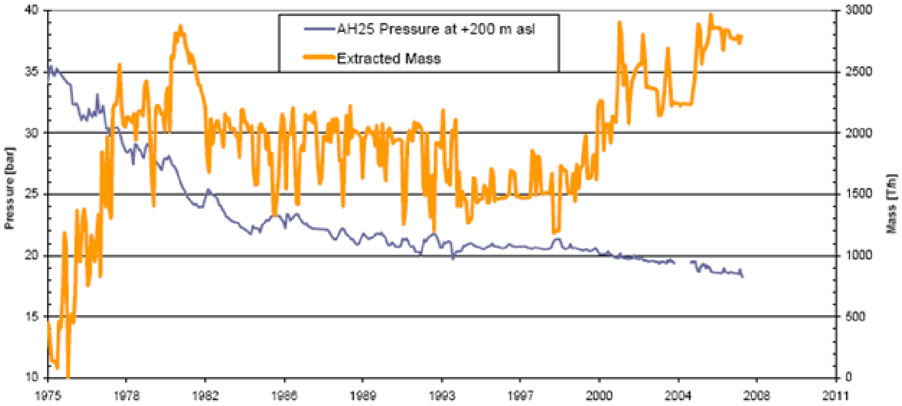


FIGURE 4: Reservoir pressure in the Ahuachapan field

After 1984, the operation programme was changed, and only units 1 and 3 were run simultaneously in commer-cial operation with a maximum power output of 65 MW; with Unit 2 on standby or as a backup as there was not enough steam to run the three units at the same time. However, more recently, new sites in the southern part of the actual production zone were evaluated to look for more steam to bring the third unit into production. In 2005, all 3 units were put into operation again, increasing the total output from 65 to 80 MW at the cost of a reservoir pressure decline of almost 1 bar. In 2005, a large mass extraction test was carried out (March-June) and Unit 2 was used as “base load”. Since November 2005, the three units have been in continuous operation (Rodriguez, 2007). Figure 4 shows the evolution of the reservoir pressure in Ahuachapan field.

2.2 Operation characteristics in Ahuachapan power plant

The energy produced from the Ahuachapan plant is the result of the operation of two single-flash condensing units with an output of 30 MW each, both supplied by Mitsubishi. The full load steam consumption of these turbines is 520 tons/h (144 kg/s) of saturated steam, at a pressure of 4.6 bar entry-g. The steam comes from two pressurized tanks called steam headers that collect the steam produced by a number of producing wells (Figure 5).

Direct contact barometric condenser is located at the exit of the turbine, where cooled water is sprayed to condense the exhaust steam. This water comes from a cross-flow, forced draft cooling tower with five cells. The total flow of the cooling water is approximately 8650 m^3/h and the ambient temperature is 27°C; the average pressure in the condenser is 0,085 bar. The condenser is connected to a gas extraction system, such as steam-jet ejectors, which has a cooling system that cools 0.2% by weight of non-condensable gases that accompany geothermal steam (Figure 5). The gas extraction system has two stages (an intercooler condenser and an after condenser) to operate a flow of 4100 kg/h of steam to compress gas from the vacuum in the condenser to external weather conditions in the discharge zone.

The turbines are attached directly to a synchronous generator with a brushless exciter and a closed air cooling system to prevent contamination of the copper conductors by hydrogen sulphide (H_2S). The nominal capacity of the generators is 35,000 kVA with a power factor of 0.85. The voltage output of the generator is 13.8 kV, which is connected to the national network of 115 kV through a step-up transformer located at the substation (Figure 5).

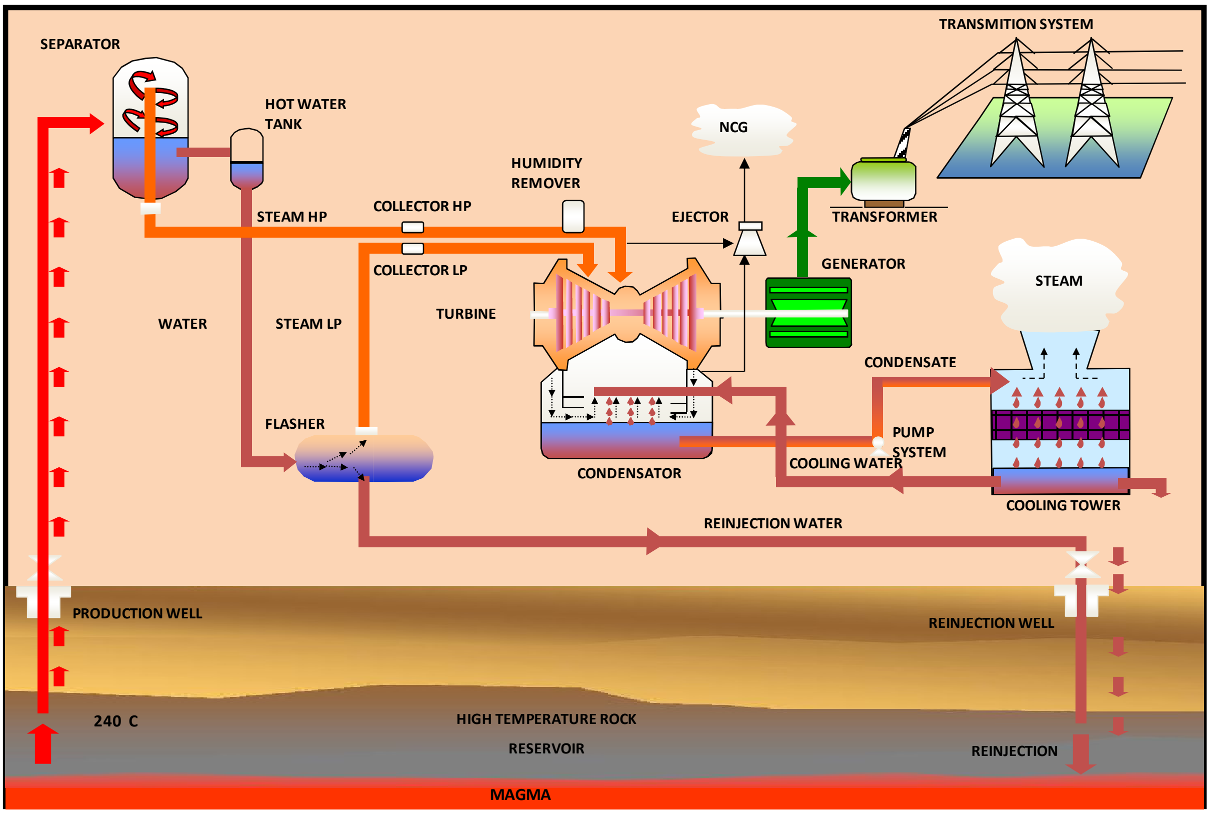


FIGURE 5: Simplified process flow diagram for a geothermal power plant

The third unit of the plant is a 35 MWe, double-flash unit supplied by Fuji and went into commercial operation in 1981. Unlike the other two units, this one uses a lower steam pressure (1.5 bar-a) in addition to the medium-pressure steam; the low-pressure steam being obtained from a second flashing of the geothermal fluid. Water is separated at the two low-pressure separators (flashers) obtaining the low-pressure steam, which flows through the low-pressure collector to the entrance of turbine. With this change, the output of the plant was increased by 20%. The third turbine unit has seven stages and operates at a speed of 3600 RPM. The MP steam required is 170 tons/h at 5.6 bars while the steam BP is 145 tons/hour at 1.5 bar to generate at the full capacity of the synchronous generator, i.e. 40,000 kVA at a power factor of 0.875. This generator is air-cooled and the excitation system is of the brushless type (Figure 5) (Amaya, 2004).

2.3 Mechanical equipment installed in Ahuachapan power plant

2.3.1 Steam production and transmission

At present, 50 wells have been drilled in the Ahuachapán-Chipilapa area. Of these, 17 are currently connected to the power plant for steam production, and 5 wells are connected for injection. Wells AH-1 and AH-7 are connected but they are not able to produce steam due to low wellhead pressure. Wells AH-25 and AH-30 are normally used to monitor the reservoir pressure, wells AH-32st and AH-35C are scheduled to be connected later in 2007, and other wells are used to monitor and characterise the system, or are used as standby producers. At least 6 wells have been abandoned (AH-3, AH-10, AH-11, AH-12, CH-A, CH-A1). Figure 6 gives the location of wells in the geothermal field.

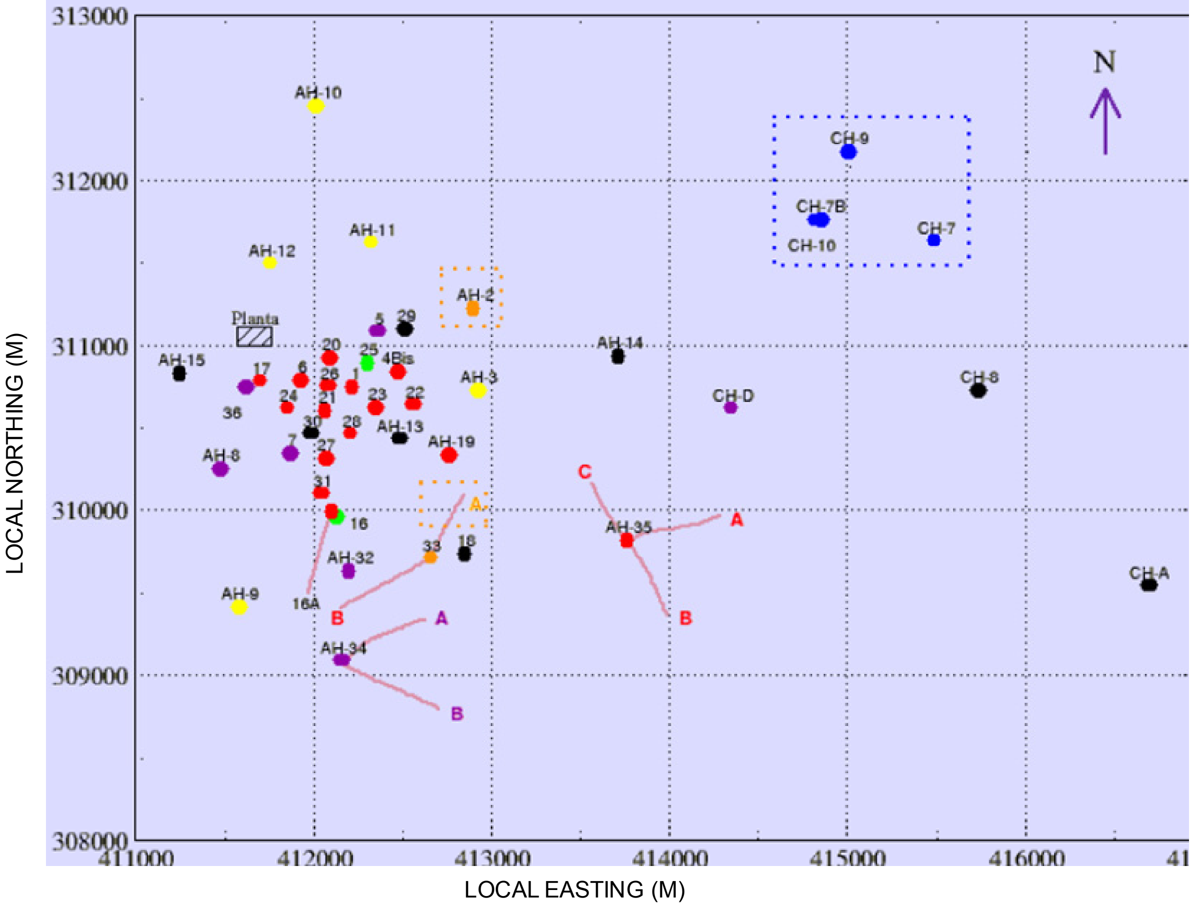


FIGURE 6: Well locations in the Ahuachapan geothermal field

The maintenance of all the mechanical equipment installed is carried out by a group of 7 people who are directly commanded by the area coordinator. The maintenance programme is planned in coordination with the people in charge of the maintenance activities in the power station as well as with the person in charge of the operation of the plant (Rodriguez, 2007).

FIGURE 7: The machinery room in the Ahuachapan power plant

2.3.2 Turbine and auxiliaries

The turbine is one of the most important pieces of equipment for a geothermal plant and also one of the most expensive (Figure 7 shows the turbine).

According to records, the turbine is the piece of equipment which needs the most time to overhaul. For this reason, an analysis of how to reduce the time needed for a turbine overhaul in Ahuachapan I was done. Some of the main parts of the turbine are:

Rotor, stationary blades, main oil pump, auxiliary oil pump, outer casing, inner casing, coupling bolts, turning gear, overpressure rupture disks, condenser, bearings, gaskets, oil sealing, storage tank, steam strainer, barometric pipe and over-speed safety device.

2.3.3 Cooling system

The cooling water system is composed of the cooling tower, the main circulation water pumps, the cooling pumps and the system of auxiliary pumps. During an overhaul, a mechanic inspects the boxes of fans in the cooling tower; these are dismantled to verify internal conditions.

The main circulation water pump is considered very important as its operation is necessary to obtain full power production of the unit. It is possible to operate the unit with only one pump but to do so results in an important loss in efficiency, on the order of 60 % of the rated output for these units.

2.3.4 Gas extraction system

The gas extraction system was designed to operate with two steam-jet ejectors; the steam for this system is taken directly from the main steam line. Two other steam-jet ejectors are mainly used for a backup system; these ejectors were designed to operate with a minimum steam flow of 4100 kg/h to extract non-condensable gases from the condenser. In year 2000, Ahuachapan installed a new vacuum pump because the amount of gas increased and the original system began to lose its efficiency.

At present, the normal operation of the non-condensable gas extraction system is made with a vacuum pump and the ejector system described above is in standby. When the unit works with the old ejector system, almost 2 MWe of load are lost because of the consequent decrease of the condenser vacuum.

Some of the main parts of the old gas extraction system are: four steam-jet ejectors, two auxiliary water pumps, and valves. The newer system is composed of one ejector, valves, a vacuum pump, a reducer gear box, and a lubrication water pump.

2.3.5 Generator

Normally, the disassembly and internal inspection of this equipment is necessary after four years of continuous operation; it is the responsibility of the mechanics to disassemble and inspect all mechanical components, while the electrical aspects like insulation condition assessment, cleaning and testing is the responsibility of the electricians. When the electrical inspection is finished, the mechanics begin re-assembling the equipment. A summary of the main components of these processes is shown in Table 1. Only the major components under each system are presented.

3. TYPES OF MAINTENANCE

3.1 General information

What is maintenance and why is it performed? Past and current maintenance practices in both the private and governmental sectors would imply that maintenance is the action associated with equipment repair after it is broken. The dictionary defines maintenance as follows: “the work of keeping something in proper condition; upkeep.” This would imply that maintenance should be action taken to prevent a device or component from failing or to repair normal equipment degradation,

TABLE 1: Information about the systems, equipment and components

Main systems	Main equipment	Main components
Steam conduction and transmission	Wellhead, separator station, steam transmission and water transmission	Master valves, flow control valve, two-phase pipeline. Separator vessel, pressure relief device, level control. Steam pipe, condensate drains, steam pressure, controllers, steam driers, steam flow meters. Hot water pipeline, hot water pressure relief
Turbine and auxiliaries	Inlet devices, steam turbine and oil system	Steam strainer, emergency and governor valves rotor, nozzles, diaphragms, bearings, casing, packing gland seals oil pumps, servomotors, oil pipes.
Cooling system	Cooling towers and water pumps condenser	Fans, motors, gear reducers, structure, fills, cold water ponds, strainers. Large hot well pumps and motors, auxiliary pumps. Condenser heat exchangers, nozzles, gas cooling.
Gas extraction system	Steam jet ejector and vacuum pump	Control valves, isolating valves, nozzles, intercoolers. Vacuum pump and motor, water seal pump and motor gear reducer box.
Generator and electrical system	Generator, transformers and protection	Rotor, stator, exciter, bearings, coolers. Step up transformers, station transformers, relays, switchgears.

experienced with the operation of the device, in order to keep it in proper working order. Unfortunately, data obtained in many studies over the past decade indicate that most private and government facilities do not expend the necessary resources to maintain equipment in proper working order. Rather, in the design life of most equipment, it requires periodic maintenance. Belts need adjustment, alignment needs to be maintained, and proper lubrication of rotating equipment is required, and so on. In some cases, certain components need replacement. Maintenance that can be performed to ensure equipment reaches or exceeds its design life has been developed in the United States. In addition to waiting for a piece of equipment to fail (reactive maintenance), preventive maintenance, predictive maintenance, or reliability-centred maintenance are utilized (Sullivan et al., 2002).

3.2 Preventive maintenance

Preventive maintenance can be defined as follows: Actions performed on a time- or machine-run-based schedule that detect, preclude, or mitigate degradation of a component or system with the aim of sustaining or extending its useful life through controlling degradation to an acceptable level. The U.S. Navy pioneered preventive maintenance as a means to increase the reliability of their vessels. By simply expending the necessary resources to conduct maintenance activities intended by the equipment designer, equipment life is extended and its reliability is increased. In addition to an increase in reliability, dollars are saved compared to that of a programme that just uses reactive maintenance. Studies indicate that these savings can amount to as much as 12-18%, on average.

Depending on facilities' current maintenance practices, present equipment reliability, and facility downtime, there is little doubt that many facilities, that rely only on reactive maintenance, could save much more than 18% by instituting a proper preventive maintenance programme.

While preventive maintenance is not the optimum maintenance programme, it does have several advantages over that of a purely reactive programme. Main advantages and disadvantages for preventive maintenance are shown in Table 2. By performing the preventive maintenance as the equipment designer envisioned, equipment life will be extended closer to design. This translates into dollar savings. Preventive maintenance (lubrication, filter change, etc.) will generally run the equipment more efficiently, resulting in dollar savings. While if catastrophic failures are not prevented, the number of failures will increase. Minimizing failures translates into maintenance and capital cost savings (Sullivan et al., 2002).

TABLE 2: Advantages and disadvantages of preventive maintenance

Advantages	**Disadvantages**
Cost effective in many capital intensive processes. Flexibility for adjustment of maintenance periodicity. Increased component life cycle. Energy savings. Reduced equipment or process failure. Estimated 12-18% cost savings over reactive maintenance programme.	Catastrophic failures still likely to occur. Labour intensive. Includes performance of unneeded maintenance. Potential for incidental damage to components in conducting unneeded maintenance.

3.3 Reactive maintenance

Reactive maintenance is basically the "run it till it breaks" maintenance mode. No actions or efforts are taken to maintain the equipment as the designer originally intended to ensure design life is reached. Studies as recent as the winter of 2000 indicate this is still the predominant mode of maintenance in the United States. The referenced study breaks down the average maintenance programme as follows:

- Reactive >55%
- Preventive 31%
- Predictive 12%
- Other 2%

Note that more than 55% of maintenance resources and activities of an average facility are still reactive. Advantages to reactive maintenance can be viewed as a double-edged sword. If new equipment has been installed, minimal incidents or failure will be experienced. If the maintenance programme is purely reactive, manpower dollars will not be expended or incur capital cost until something breaks.

Since associated maintenance costs are not present, this period can be seen as a period of saving money (Sullivan et al., 2002). The downside is reality. In reality, during the time engineers believe the company is saving maintenance and capital costs, the truth is that the company is spending more dollars than if they had undertaken a different maintenance approach. More money associated with capital costs has been spent because, while waiting for the equipment to break, the life of the equipment has been reduced resulting in more frequent replacement. Failures in primary devices are produced by failures in secondary devices, producing increased cost. Incurred costs for primary device replacement can be avoided if the maintenance programme is more proactive. Labour costs associated with repair will probably be higher than normal because the failure will most likely require more extensive repairs than would have been required if the piece of equipment had not been run to failure. Chances are the piece of equipment will fail during off hours or close to the end of the normal workday. If it is a critical piece of equipment that needs to be back on-line quickly, maintenance overtime costs will increase. Since expectations are to run equipment to failure, a large material inventory of repair parts would be required. This cost could be minimized under a different maintenance strategy. Main advantages and disadvantages for reactive maintenance are shown in Table 3.

TABLE 3: Advantages and disadvantages of reactive maintenance

Advantages	Disadvantages
Low cost.	Increased cost due to unplanned downtime of equipment.
	Increased labour cost, especially if overtime is needed.
Less staff.	Cost involved with repair or replacement of equipment.
	Possible secondary equipment or process damage from equipment failure.
	Inefficient use of staff resources.

3.4 Predictive maintenance

Predictive maintenance can be defined as follows: Measurements that detect the onset of a degrading mechanism, thereby allowing causal stressors to be eliminated or controlled prior to any significant deterioration in the component's physical state (Sullivan et al., 2002). Results basically indicate current and future functional capability. Predictive maintenance differs from preventive maintenance by basing maintenance need on the actual condition of the machine rather than on some preset schedule. In other words, preventive maintenance is time-based. Activities such as changing lubricant are based on time, like calendar time or equipment run time. For example, most people change the oil in their vehicles every 3,000 to 5,000 miles travelled. This is effectively basing the oil change needs on equipment run time. No concern is given to the actual condition and performance capability of the oil. It is changed because it has been scheduled. This methodology would be analogous to a preventive maintenance task. If, on the other hand, the operator of the car discounted the vehicle run time and had the oil analyzed at some facility to determine its actual condition and lubrication properties, he/she might be able to extend the time to the next oil change until the vehicle had travelled 10,000 miles. This is the fundamental difference between predictive maintenance and preventive maintenance, whereby predictive maintenance is used to define a needed maintenance task based on quantified material/equipment condition. The advantages of predictive maintenance are many. A well-orchestrated predictive maintenance programme will all but eliminate catastrophic equipment failures. It will be able to schedule maintenance activities to minimize or delete overtime cost. It will be able to minimize inventory and order parts, as required, well ahead of time to support the downstream maintenance needs. Optimizing the operation of the equipment, saving energy cost and increasing plant reliability could result. Studies have estimated that a properly functioning predictive maintenance programme can provide a savings of 8-12% over a programme utilizing preventive maintenance alone. Depending on a facility's reliance on reactive maintenance and material condition, it could easily recognize savings opportunities exceeding 30-40%. In fact, independent surveys indicate the following industrial average savings resultant from initiation of a functional predictive maintenance programme:

- Return on investment: 10 times
- Reduction in maintenance costs: 25-30%
- Elimination of breakdowns: 70-75%
- Reduction in downtime: 35-45%

- Increase in production: 20-25%.

On the down side, initiating predictive maintenance is not inexpensive. Much of the equipment required costs in excess of USD 50,000. Training of in-plant personnel to effectively utilize predictive maintenance technologies requires considerable funding. Programme development requires an understanding of predictive maintenance and a firm commitment to make the programme work by all facility organizations and management. Main advantages and disadvantages for predictive maintenance are shown in Table 4.

TABLE 4: Advantages and disadvantages of predictive maintenance

Advantages	**Disadvantages**
Increased component operational life/availability. Allows for pre-emptive corrective actions. Decrease in equipment or process downtime. Decrease in costs for parts and labour. Better product quality. Improved worker and environmental safety, improved worker moral. Energy savings. Estimated 8-12% cost savings over preventive maintenance programme.	Increased investment in diagnostic equipment. Increased investment in staff training. Savings potential not readily seen by management.

4. TYPES OF MAINTENANCE IN AHUACHAPAN POWER PLANT

The types of maintenance in the Ahuachapan power plant are preventive maintenance and predictive maintenance.

4.1 Preventive maintenance

For preventive maintenance, this type of management system includes computerized/manual procedures (written/updated, audited): Written programmes of written routine activities are developed, and there is computerized maintenance management software (MAXIMO). The software for maintenance administration is similar to all such programmes. Their objective is to provide information as needed to realise the activities corresponding to maintenance. The programme can follow the recommendations given by the machinery manufacturer as well as being based on the experience collected by the maintenance and operating personnel. It also facilitates obtaining information to determine which pieces of equipment, at a certain moment, demand more man-hours and money. It is also possible to obtain information about the amount of work orders for preventive, corrective and predictive work. Figure 8 shows the control of preventive maintenance in Ahuachapan.

4.2 Predictive maintenance

The common maintenance procedures carried out under predictive maintenance include vibration analysis, thermography, ultrasonic and oil analysis. Table 5 gives a summary of predictive maintenance actions and their applications. The first four are common procedures and are described in detail.

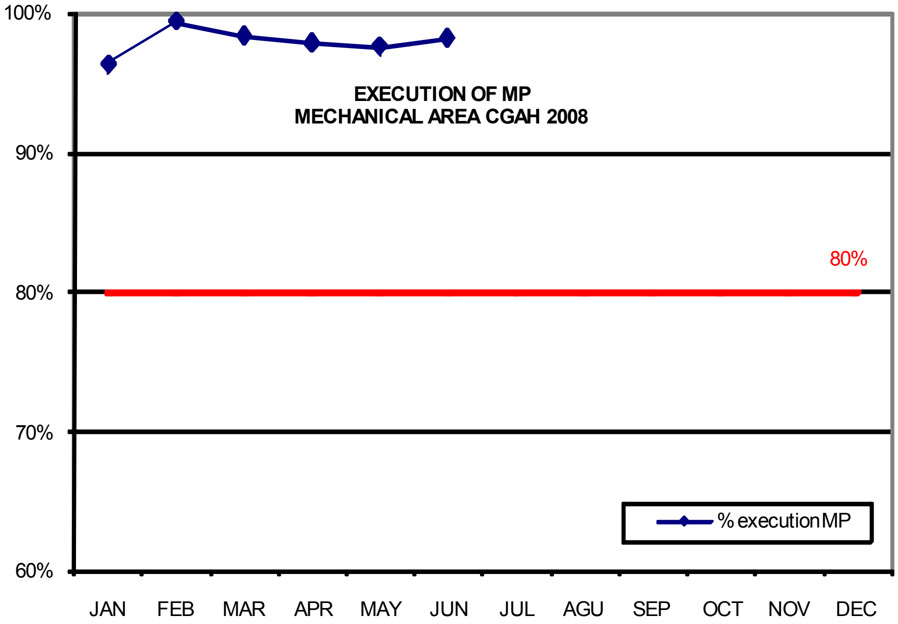


FIGURE 8: Control of preventive maintenance in Ahuachapan power plant

TABLE 5: Advantages and disadvantages of preventive maintenance in Ahuachapan power plant

No.	Predictive procedure	Applications
1	Vibration analysis	Misalignment, out of balance weights, wear of bearings etc.
2	Thermography analysis	Overloading, excessive friction or wear, abnormal electric resistance.
3	Oil analysis	Contamination, breakdown of lubrication properties, signs of wear.
4	Current measurement	Electric overloads, faulty bearings, current leakage.
5	Visual inspection	General defects that can be detected by sight, hearing and touch.
6	Insulation tests	Check status of electric insulation.
7	Power rate	Bearing failures, damaged turbine blades, vacuum loss.
8	Voltage measurement	Brush failure, faulty excitation, insulation failure.

Vibration analysis: Software for vibrations analysis is used in predictive routines. In the main water circulation pumps, equipment is inserted to obtain vibrations without having to execute measurement routines with portable equipment. This facilitates data collection on the conditions of pumps operations; this equipment is considered important for optimal operation of the generating units. With this equipment, it is possible to observe the magnitudes of pump vibrations as well as the diagrams to make an analysis, all while still in the control room (Figure 9).

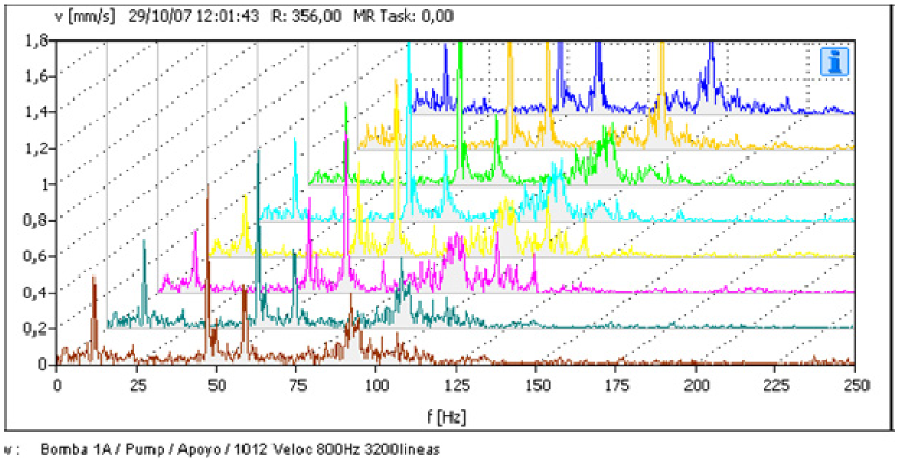


FIGURE 9: Operation condition register

5. OVERHAULS IN AHUACHAPAN GEOTHERMAL POWER PLANT

5.1 General information

Unit overhaul is carried out after every two years of continuous operation. This maintenance usually takes four to six weeks to complete, depending on which unit is being maintained. For this type of maintenance, it is necessary to optimize time and costs, time, because when one geothermal unit is shut down the electrical system in El Salvador requires putting thermal plants online, and the electricity produced by these plants is considerably more expensive (Lopez, 2006).

When Ahuachapan power plant overhauls any unit, it is necessary to prepare tools, possible spare parts and to hire external personnel to carry out the work. Due to the conditions of the energy system of the country, it is necessary to schedule overhauls so that the power system operator can guarantee the service of energy. He evaluates if it is possible to authorize it or not; this depends on the generating conditions of the hydroelectric plants, since otherwise a great amount of thermal production would be required, which would cause the price of electrical power to go up.

5.2 Manpower for overhauls in the mechanical area

The organizational charts of the mechanical area are described here below. Figure 10 shows permanent workers only. In the power plant, during an overhaul, it is necessary to hire personnel with the required skills to carry out the work. The number of people hired depends on the scope of the maintenance and on the time needed to accomplish it. The programme is realised with the participation of the involved personnel. Different areas and equipment require different expertise. For example, in the cooling tower, mechanics are required to disassemble the fan gear boxes for inspection. Electricians are required to disassemble motors for inspection. On occasion, the person in charge of the tower needs to make changes in the zone which requires very good coordination to prevent collisions between workers and avoid subsequent delays. Thus, it is important to define the maintenance programme to establish a clear view of the objectives and the time to execute it. After designing this guide, it is possible to determine the optimum number of personnel to be contracted to do the work.

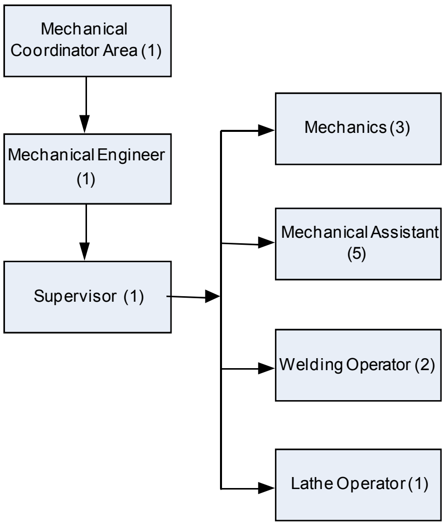


FIGURE 10: Chart of mechanical manpower in Ahuachapan

In order to insure the necessary knowledge and expertise are available in the work area, a programme has been developed through which all personnel involved in the different tasks are enrolled sequentially; thus, at any point in time, there is not just one person with the knowledge and training of the different maintenance procedures to be carried out in the different areas of the plant. This programme has generated very good results. Since the manpower needed is based on the kind of work needing to be done at any particular time, rotation of qualified personnel is beneficial.

5.3 Activities previous to an overhaul

When an overhaul is programmed, it is necessary to be prepared with spare parts and consumable materials that are considered strategic. By spare parts we mean parts that are not readily available on the local market and the lack of which would cause an enormous delay in the overhauling programme, Expendable materials can usually be easily acquired. Table 6 shows some of the materials that are considered strategic.

After assuring the availability of strategic spare parts, one must also evaluate the tools needed; some of them are considered special and procurement time of such can be long, so if the tools are not prepared in advance, delays in the maintenance schedule could occur. The tools must be in good working order; using damaged tools can lead to a high risk of accidents for both personnel and equipment. For these reasons, tools in bad condition should be replaced.

TABLE 6: Main equipment and spare parts necessary previous to an overhaul in Ahuachapan power plant

Item	Equipment	Spare parts
1	Turbine	Radial bearing, exhaust diaphragm, trust bearing. Expansion joint in steam line and earth brush.
2	MOP	Radial bearing, thrust bearing, impeller, shaft and earth brush.
3	Generator	Radial bearing, earth brush.
4	Exiter	Radial bearing.
5	Emergency and governing valves	Packing, pistons sleeves and shaft.
6	Main circulation water pumps	Intermediate shaft, sleeve, radial bearing, thrust bearing, impeller, coupling.
7	Gear reducer in cooling tower	Transmission shaft, gears, fans, oil, coupling, oil seal.
8	Extraction system	Oil seal, oil, gears, coupling systems.

The following steps describe the maintenance programme (The programme is shown in Appendix I). This programme makes it possible to determine the number of personnel necessary for the job; it is also important to find ways in which tasks can be performed simultaneously to reduce the work time. It is also important to discuss this programme with the people in charge of other work areas as often their work takes place in the same area where maintenance needs to be performed, which may cause some delays (Lopez, 2006). Figure 11 gives the time required for an overhaul operation in each system; as can be seen, the time needed to overhaul the turbine is the greatest.

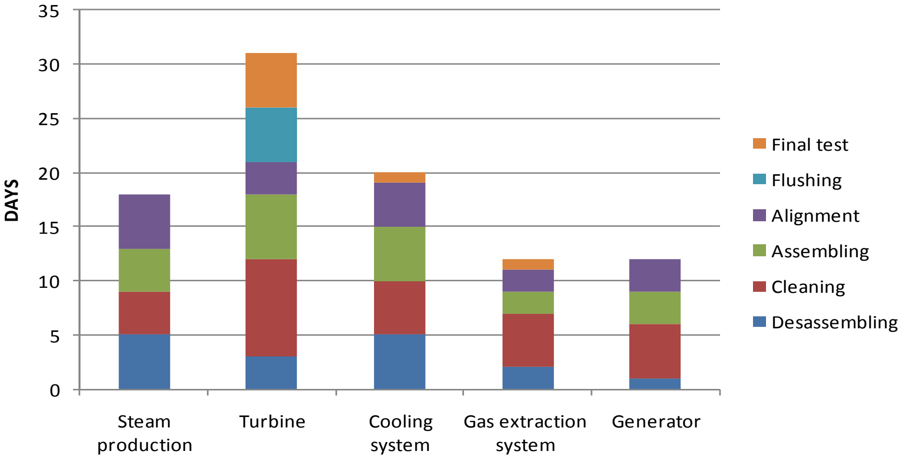


FIGURE 11: Register of time for systems in overhaul

5.4 Manpower costs for overhauls in Ahuachapan

The information in Table 7 shows the total number of mechanics and aides needed and the associated costs during an overhaul (Lopez, 2006). In this case the work programme shows that 36 external workers need to be hired; adding the 14 permanent workers, a total of 50 persons will be needed.

TABLE 7: Manpower cost (in USD) in overhaul of Ahuachapan power plant

No.	**Position carrying out work**	**Human resource**	**Salary (USD)**	**200%**		**250%**		**50%**		**Total (USD)**	**Salary / hour**
				Hours	**Cost**	**Hours**	**Cost**	**Hours**	**Cost**		
Mechanical maintenance group for turbine											
1	Mech. supervisor	Permanent	1100	112	513.3	16	73.3	20	45.8		4.58
2	Mechanic	Permanent	875	112	408.3	16	58.3	20	36.5		3.65
3	Mechanical helper	Permanent	750	112	350.0	16	50.0	20	31.3		3.13
4	Mechanic	Permanent	800	112	373.3	16	53.3	20	33.3		3.33
5	Welding operator	Permanent	800	112	373.3	16	53.3	20	33.3		3.33
6	Mechanic	External recourse	400	112	186.7	16	26.7	20	16.7		1.67
7	Mechanic	External recourse	400	112	186.7	16	26.7	20	16.7		1.67
8	Mechanic	External recourse	400	112	186.7	16	26.7	20	16.7		1.67
9	Mechanic	External recourse	400	112	186.7	16	26.7	20	16.7		1.67
10	Mechanic	External recourse	400	112	186.7	16	26.7	20	16.7		1.67
11	Mechanic	External recourse	400	112	186.7	16	26.7	20	16.7		1.67
Total			**6725**		**3138**		**448.3**		**280.2**	**10592**	
Turbine cleaning group											
12	Mechanic	External recourse	400	112	186.7	16	26.7	20	16.7		1.67
13	Mechanical helper	External recourse	300	112	140.0	16	20.0	20	12.5		1.25
14	Mechanical helper	External recourse	300	112	140.0	16	20.0	20	12.5		1.25
15	Mechanical helper	External recourse	300	112	140.0	16	20.0	20	12.5		1.25
16	Mechanical helper	External recourse	300	112	140.0	16	20.0	20	12.5		1.25
17	Mechanical helper	External recourse	300	112	140.0	16	20.0	20	12.5		1.25
18	Mechanical helper	External recourse	300	112	140.0	16	20.0	20	12.5		1.25
19	Mechanical helper	External recourse	300	112	140.0	16	20.0	20	12.5		1.25
20	Mechanical helper	External recourse	300	112	140.0	16	20.0	20	12.5		1.25
Total			**2800**		**1307**		**186.7**		**116.7**	**4527**	
Cooling tower group											
21	Mechanic	Permanent	875	112	408.3	16	58.3	20	36.5		3.65
22	Mechanical helper	Permanent	750	112	350.0	16	50.0	20	31.3		3.13
23	Mechanic	External recourse	400	112	186.7	16	26.7	20	16.7		1.67
24	Mechanic	External recourse	400	112	186.7	16	26.7	20	16.7		1.67
25	Mechanical helper	External recourse	300	112	140.0	16	20.0	20	12.5		1.25
26	Mechanical helper	External recourse	300	112	140.0	16	20.0	20	12.5		1.25
Total			**3025**		**1412**		**201.7**		**126.0**	**4890**	
Main circulation water pump group											
27	Mechanic	Permanent	875	112	408.3	16	58.3	20	36.5		3.65
28	Mechanical helper	Permanent	750	112	350.0	16	50.0	20	31.3		3.13
29	Mechanic	External recourse	400	112	186.7	16	26.7	20	16.7		1.67
30	Mechanic	External recourse	400	112	186.7	16	26.7	20	16.7		167
31	Mechanic	External recourse	400	112	186.7	16	26.7	20	16.7		1.67
32	Mechanical helper	External recourse	300	112	140.0	16	20.0	20	12.5		1.25
33	Mechanical helper	External recourse	300	112	140.0	16	20.0	20	12.5		1.25
Total			**3425**		**1598**		**228.3**		**142.7**	**5537**	
Steam line group											
34	Mechanic	Permanent	750	112	350.0	16	50.0	20	31.3		3.13
35	Mechanic	External recourse	400	112	186.7	16	26.7	20	16.7		1.67
36	Mechanic	External recourse	400	112	186.7	16	26.7	20	16.7		1.67
37	Mechanic	External recourse	400	112	186.7	16	26.7	20	16.7		1.67
38	Mechanical helper	External recourse	300	112	140.0	16	20.0	20	12.5		1.25
39	Mechanical helper	External recourse	300	112	140.0	16	20.0	20	12.5		1.25
40	Mechanical helper	External recourse	300	112	140.0	16	20.0	20	12.5		1.25
41	Mechanical helper	External recourse	300	112	140.0	16	20.0	20	12.5		1.25
42	Mechanical helper	External recourse	300	112	140.0	16	20.0	20	12.5		1.25
43	Mechanical helper	External recourse	300	112	140.0	16	20.0	20	12.5		1.25
44	Mechanical helper	External recourse	300	112	140.0	16	20.0	20	12.5		1.25
Total			**4050**		**1890**		**270.0**		**168.8**	**6548**	
Welding work group											
45	Mech. supervisor	Permanent	1100	112	513.3	16	73.3	20	45.8		4.58
46	Mechanic	Permanent	875	112	408.3	16	58.3	20	36.5		3.65
47	Mechanical helper	Permanent	750	112	350.0	16	50.0	20	31.3		3.13
48	Mechanic	Permanent	800	112	373.3	16	53.3	20	33.3		3.33
49	Welding operator	Permanent	800	112	373.3	16	53.3	20	33.3		3.33
50	Mechanic	External recourse	400	112	186.7	16	26.7	20	16.7		1.67
Total			**4725**		**2205.0**		**315.0**		**196.9**	**7638.8**	

Furthermore, the work is scheduled from Monday to Sunday, twelve hours a day Monday through Saturday, and 5 hours on Sunday. According to this calculation, the manpower cost is: **USD 39,732.**

The cost for lost generation is calculated by considering:

- The turbine is 30 MWe
- One MWe is equal to USD 50
- The maintenance programme is 30 days
- Lost money for no generation during maintenance = 30 × 50 × 24 × 30
- The cost of lost generation for one month is USD 1,080,000.

In this report the total overhaul cost is the sum of the costs of lost generation and the manpower employed. The total cost in this case is: 1,080,000 + 39,281 = **USD 1,120,000.**

6. SVARTSENGI POWER PLANT (ICELAND)

6.1 General information

The Svartsengi power plant is located on the Reykjanes Peninsula about 50 km away from Reykjavík in a high-temperature geothermal field (Figure 12). The geothermal field is near the town of Grindavík. Today it supplies electricity to the inhabitants in the region and contributes a considerable amount of electricity to the national grid, although the power plant was initially constructed as a heating utility. The rise of oil prices in the world greatly influenced the geothermal exploration in the area.

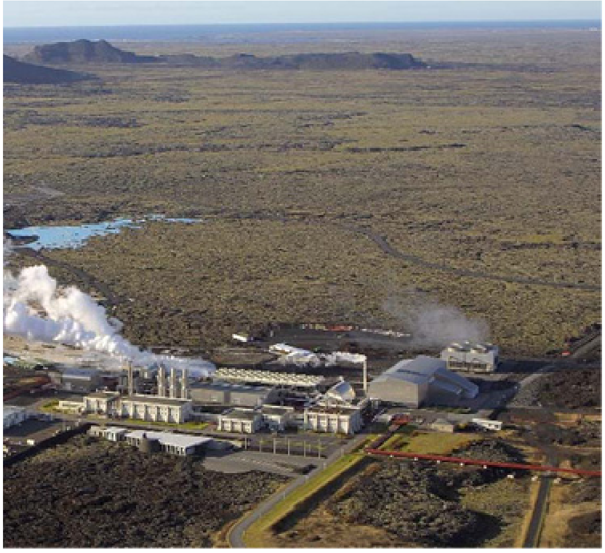


FIGURE 12: The Svartsengi power plant

The Svartsengi geothermal plant is a combined heat and power (CHP) plant. The heating plant supplies hot water to a district heating system (hitaveita) serving 20,000 people. The total installed capacity of the combined plants at Svartsengi is 76.4 MW of electrical power, and 150 MWth in the form of hot water. Local factors like the geothermal system, location, weather and climate highly influence the maintenance of the geothermal plant. The first production at Svartsengi started in 1976, 28 years ago. Since the beginning, the Svartsengi operation and maintenance staff has kept the plant in good order.

The plant was built in several stages. The reliability of the heating plant is extremely important. There is no "spare" heating plant for the district heating system. But the electrical system is connected to the national grid system where redundancies and "spinning reserves" are accessible (of course this costs some money). To ensure a high level of availability, the heat exchange process in Svartsengi is split into several flow streams with many internal redundancies. Turbine downtime means lost money (Thórólfsson, 2005).

6.2 Mechanical equipment installed and manpower

Svartsengi power plant has six main power stations:

- *Plant I:* The oldest plant, commissioned in 1977, it produces both electricity and hot water. It has four units with a capacity of 12.5 MWth each (to heat cold water from 5 to 125°C), and two AEG back pressure turbines with a capacity of 1 MWe each.

- *Plant II:* Commissioned in 1981, it produces only hot water. This plant has three units with a capacity of 25 MWth each (to heat cold water from 5 to 125°C).

- *Plant III:* Commissioned in 1980, it produces only electricity. This plant has one Fuji back-pressure turbine with a capacity of 6 MWe; the back-pressure steam is transferred to the Ormat units in Plant IV.

- *Plant IV:* Commissioned in 1989-1992, produces only electricity. This plant has seven Ormat organic turbines, 1.2 MWe each.

- *Plant V:* Commissioned in year 1999-2000 to replace Plant 1. This plant produces hot water, 75 MWth, and electricity, in one Fuji condensing turbine with a capacity of 30 MWe.

- *Plant VI:* The latest power station, commissioned in year 2007. This plant has one Fuji condensing turbine with a capacity of 30 MWe.

The plant maintenance and operating staff consists of 22 men who regularly attend to 12 turbines, specifically 5 steam turbines and 7 Organic Rankine Cycle (ORC) units. In addition, they look after 36 cooling fans, 17 geothermal wells and wellheads, 70 control valves, 100 pumps, 20 km pipelines, and thousands of valves that require maintenance (Tessema, 2002).

6.3 Types of maintenance in Svartsengi power plant

6.3.1 Preventive maintenance

The power station uses DMM software to help manage the maintenance system. The maintenance manager uses the software in sending work orders to the operators and receiving reports from them. The software is designed to tailor-make interfaces with SCADA or other systems to suit all requirements. DMM has been especially designed to handle every aspect of asset registry and work management. It gathers and organizes valuable information that can be used in establishing best practices. Maintenance work will result in lower cost, minimum down time and extended equipment lifetime. The end result is an improved return on investment within the company (Tessema, 2002).

6.3.2 Predictive maintenance

Svartsengi has other advanced maintenance equipment. Table 8 shows the most important techniques of predictive maintenance.

TABLE 8: Types of predictive maintenance in Svartsengi power plant

No.	Predictive procedure	Applications
1	Vibration analysis	Misalignment, out of balance weights, wear of bearings etc.
2	Thermography analysis	Overloading, excessive friction or wear, abnormal electric resistance.
3	Oil analysis	Contamination, breakdown of lubrication properties, signs of wear.
4	Visual inspection	General defects that can be detected by sight, hearing and touch.
5	Insulation tests	Check status of electric insulation.
6	Power rate	Bearing failures, damaged turbine blades, vacuum loss.
7	Voltage measurement	Brush failure, faulty excitation, insulation failure.

7. OVERHAULS IN SVARTSENGI POWER PLANT, ICELAND

7.1 General information about overhauls in Svartsengi power plant

The six different plants at the Svartsengi power station were commissioned at different periods of time. The overhaul programme for each plant is based on operating conditions rather than time. Operating conditions are determined according to baroscopic test, vibration analysis, oil analysis etc. (the programme is given in Appendix I).

These systems, as well as others that are part of the predictive maintenance process, along with investments in equipment made in accordance with operating conditions, help reduce maintenance costs.

7.2 Manpower for overhauls in the mechanical area

There is no specific group under the maintenance manager responsible only for maintenance. All the technicians who operate the plant work under the maintenance manager in daily shifts.

There is no specified team for each plant. The same people maintain all six plants at Svartsengi. The shift operators are responsible for troubleshooting and emergency corrective maintenance. Condition monitoring and major corrective maintenance are done during the daily maintenance shift. Work that might involve considerable scheduling efforts in terms of job methods and major spare part resources, like overhauling the plants and working over the wells, is done by contractors and the operators. Figure 13 shows the administrative structure at Svartsengi (Tessema, 2002).

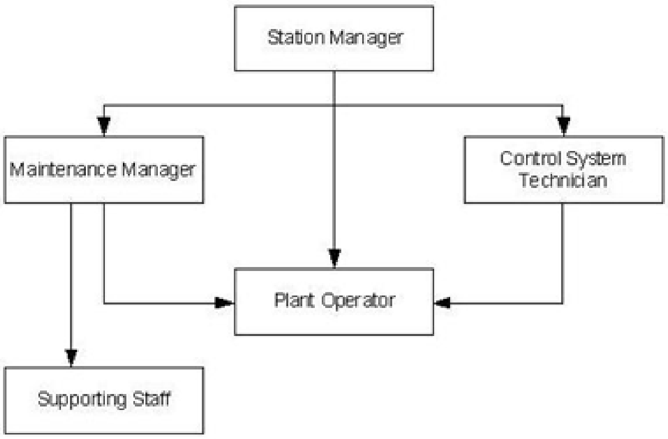


FIGURE 13: The administrative structure of the Svartsengi power plant

7.3 Manpower cost for overhauls in Svartsengi

In this study, manpower costs refer to the payments made to employees for hours spent carrying out maintenance tasks (Table 9). Other costs are considered administrative and are not part of the analysis. This study did not consider the exchange of machine parts or the expenditure in consumable materials which varies in proportion to the maintenance programme (Kwambai, 2008).

TABLE 9: Types of manpower in Svartsengi

Category of manpower	Units	Hourly rates
Top managers (decision and planning)	ISK/hr	5000
Special trained team leader (trained champion)	ISK/hr	4000
Technical specialists (data gathering and analysis)	ISK/hr	3000
Craft trained (specialized tasks)	ISK/hr	2500
General workforce (general tasks)	ISK/hr	2000

8. COMPARISON OF MAINTENANCE SYSTEMS

Table 10 compares the two plants, Ahuachapan and Svartsengi, with respect to maintenance, based on time.

TABLE 10: Comparison of overhauls in Svartsengi (SPP) and Ahuachapan (APP)

Item	Description	SPP	APP	Comments
1	Manpower in mechanical area	22	15	Svartsengi PP has 22 people working but not confined only to maintenance work. All technicians operating the plant work under the maintenance manager in daily shifts. There is no specific maintenance team for each plant. The same people maintain all six plants at SPP. APP has 15 people working in the mechanical area, but during overhauls up to 30 external personnel are hired for the programme; normally the total number of the group depends on the programme tasks.
2	Power capacity installed	76.4 MWe and 150 MWth	95 MW	SPP has 6 plants (units). APP has 3 units.
4	Age of plants	Started 1976	Started 1975	The plants are practically the same age.
5	System for administering maintenance	Software	Software	Both use software for the administration of maintenance; with these it is possible to keep a historical record of maintenance work.
6	Overhaul frequency	Depends on operating conditions	Every two years	In SPP, overhaul frequency depends on the conditions of machines. In APP, overhaul takes place every two years according to manufacturer recommendations.
7	Overhaul programme	Depends on the operating conditions	Has a set programme	In SPP the amount of overhaul work depends on the operating conditions of equipment; in APP, all equipment is considered in the overhaul.
8	Disassembling the turbine	2 days	2 days	In both PPs, the time needed for disassembling the turbine is two days.
9	Cleaning the turbine system	3 days	6 days	In SPP, an outside firm that uses a process called water blasting is hired; this requires three days. In APP, the cleaning is done manually with sandpaper so the time needed for the job is six to eight days.
10	Assembling the turbine	4 days	6 days	In SPP, mounting the turbine takes four days since much of the auxiliary equipment is not overhauled. In APP, the turbine & auxiliary equipment are all overhauled.
11	Cleaning the oil system	0 days	5 days	In SPP, the oil system is not part of the overhaul since installed equipment guarantees good oil conditions. In APP, one of the first tasks at the start of an overhaul is to transfer oil to the emergency tank in order to access the main tank for cleaning; at the end, the oil is returned to the main tank.
12	Cleaning the cooling oil system	0 days	5 days	The oil cooling system in SPP is not defined part of the overhaul; in APP, this equipment comprises 5 days of work time for the inspection and cleaning needed.
13	Cleaning the condenser	0 days	5 days	In SPP, no cleaning is needed in this system. In APP, this task is executed after turbine assembly is complete; this activity cannot be conducted simultaneously with turbine assembly for risk of accidents to personnel.
14	Turbine alignment	0 days	2 days	In SPP, after an overhaul, the turbine does not need to be realigned as the position of the generator does not change. In APP, after an overhaul, it is always considered necessary to realign the turbine; for this, normally two days are required.
15	Cleaning the generator air coolers	0 days	5 days	In SPP, this activity is not necessary. In APP, the air coolers are dismounted for cleaning; a hydrostatic pressure test is made to make sure that no leaks are present. Five days are needed for this activity.
16	Cleaning the steam strainer	1 day	6 days	SPP needs one day for inspection. In APP, the filters of the steam entrance are dismounted for inspection and cleaning. Before assembly, the main steam pipes to the turbine are inspected.

Item	Description	SPP	APP	Comments
17	Inspection of the main circulation water pumps	0 days	15 days	In SPP, the main water circulation pumps are only considered a part of the overhaul if some problem has been detected. In APP, these pumps are considered part of the overhaul, and are dismounted for inspection. The pumps are mixed flow vertical pumps with 1 stage and double floor.
18	Cooling tower work	2 or 4 days	20 days	In SPP, work here consists of an oil change of the reducing boxes and in some cases when it has registered abnormal work during operation, additional work is scheduled. In APP, this work consists of disassembling the reducing boxes for inspection of the internal parts, an oil change is done in the five boxes.
19	Inspection of the NCG extraction systems	2 days	12 days	In SPP, 2 days are needed for this inspection. In APP, 12 days are needed because of the ejector systems and vacuum pump.
20	Inspection of the main steam header	2 days	5 days	In SPP, this takes only two days; in APP, the steam header of each unit is inspected every four years. This is programmed to clean and measure internal wall thicknesses.
21	Inspection of humidity separator (steam demister)	0 days	5 days	In SPP, this is not needed. In APP, the demister is inspected during each overhaul to check the internal parts as well as to register the thicknesses.
22	Flushing the oil system	0 days	4 days	SPP has a good system for oil cleaning so flushing is not needed at the end of the overhaul. In APP, flushing is done to avoid solid particles entering the bearings and damaging during operation. For this, special filters are placed in the oil piping, and the auxiliary pump used to circulate the oil.
23	Interlock tests	1 day	2 days	Normally in SPP, the test is done when the turbine is shut down at the beginning of the overhaul; only one day is needed. In APP, all recommendations from the manufacturer are accounted for. The test is done when the overhaul is finished; two days are needed.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

In Svartsengi, much of the mechanical equipment is controlled by a predictive system and, thus, not considered part of the overhaul process. In Ahuachapan, all the mechanical equipment is overhauled. This difference between the two systems means that less time is needed for an overhaul in Svartsengi power plant.

During the overhaul, the manufacturer recommends some activities that in Svartsengi are realised during the process of commissioning a unit. But in Ahuachapan, all these tests are realised at the end of the overhaul; before putting the unit online again, devices are adjusted and tests are made to assure their good operation in order to protect the machinery.

The activity which gives the greatest time difference between Svartsengi and Ahuachapan during an overhaul is that of cleaning the parts of the turbine; in Svartsengi, this is done by an external company which uses a water blasting procedure that reduces by half the time required in Ahuachapan, where the procedure is done manually.

9.2 Recommendations

According to the comparison, the activities that could best be changed in order to reduce the time needed for overhauls in Ahuachapan are: 1) cleaning parts of the turbine (evaluate the possibility of using the Svartsengi method); 2) oil flushing. There is equipment available which can monitor and prevent the risk of solid particles damaging bearings and servomotors.

It is considered that if these techniques were implemented, it would be possible to reduce the time required for an overhaul in Ahuachapan by five days.

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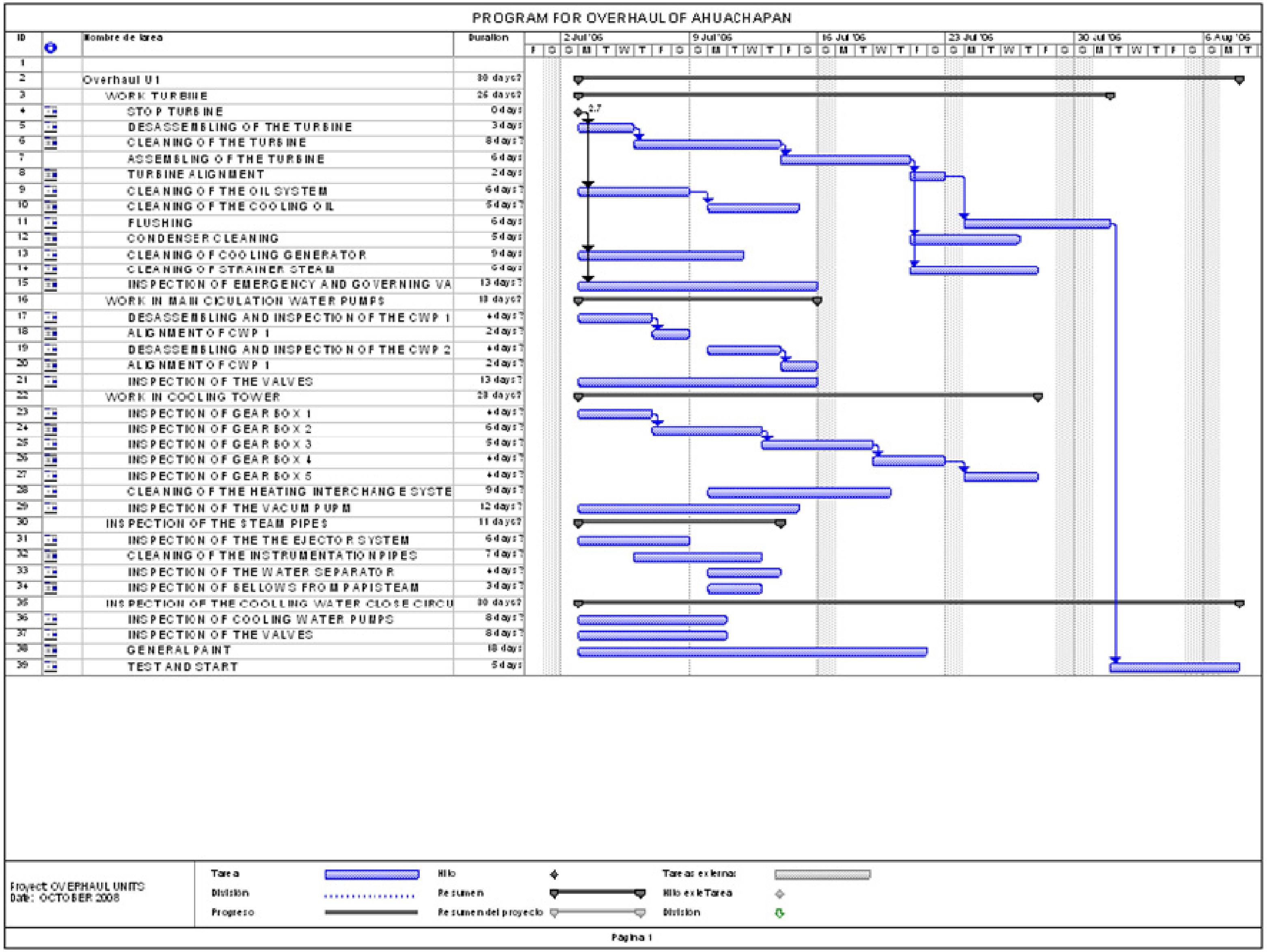
APPENDIX I: PROGRAMMES FOR OVERHAUL

A. The Ahuachapan power plant in El Salvador



PROGRAM FOR OVERHAUL OF AHUACHAPAN

ID	Nombre de tarea	Duration
1		
2	Overhaul U1	30 days?
3	WORK TURBINE	26 days?
4	STOP TURBINE	0 days
5	DESASSEMBLING OF THE TURBINE	3 days
6	CLEANING OF THE TURBINE	8 days?
7	ASSEMBLING OF THE TURBINE	6 days
8	TURBINE ALIGNMENT	2 days
9	CLEANING OF THE OIL SYSTEM	6 days?
10	CLEANING OF THE COOLING OIL	5 days?
11	FLUSHING	6 days
12	CONDENSER CLEANING	5 days
13	CLEANING OF COOLING GENERATOR	9 days
14	CLEANING OF STRAINER STEAM	6 days
15	INSPECTION OF EMERGENCY AND GOVERNING VA	13 days?
16	WORK IN MAIN CICULATION WATER PUMPS	18 days?
17	DESASSEMBLING AND INSPECTION OF THE CWP 1	4 days?
18	ALIGNMENT OF CWP 1	2 days?
19	DESASSEMBLING AND INSPECTION OF THE CWP 2	4 days?
20	ALIGNMENT OF CWP 1	2 days?
21	INSPECTION OF THE VALVES	13 days?
22	WORK IN COOLING TOWER	28 days?
23	INSPECTION OF GEAR BOX 1	4 days?
24	INSPECTION OF GEAR BOX 2	6 days?
25	INSPECTION OF GEAR BOX 3	5 days?
26	INSPECTION OF GEAR BOX 4	4 days?
27	INSPECTION OF GEAR BOX 5	4 days?
28	CLEANING OF THE HEATING INTERCHANGE SYSTE	9 days?
29	INSPECTION OF THE VACUM PUPM	12 days?
30	INSPECTION OF THE STEAM PIPES	11 days?
31	INSPECTION OF THE THE EJECTOR SYSTEM	6 days?
32	CLEANING OF THE INSTRUMENTATION PIPES	7 days?
33	INSPECTION OF THE WATER SEPARATOR	4 days?
34	INSPECTION OF BELLOWS FROM PAPISTEAM	3 days?
35	INSPECTION OF THE COOLLING WATER CLOSE CIRCU	30 days?
36	INSPECTION OF COOLING WATER PUMPS	8 days?
37	INSPECTION OF THE VALVES	8 days?
38	GENERAL PAINT	18 days
39	TEST AND START	5 days

Proyect: OVERHAUL UNITS
Date: OCTOBER 2008

Pagina 1

B. The Svartsengi power plant in Iceland