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Geothermal power plants in Italy: increasing the technological performance

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ABSTRACT

The need of increasing the efficiency of geothermal power plants has brought in last years to several evolutions in the technology of plants and in operational practices.

We describe in detail the technological solutions put in place in order to expand the characteristics of the fluids that can be used, reduce maintenance need, increase efficiency and reliability of machinery, improve operational control techniques.

With the increasing of wells depth, we find fluids that are more and more corrosive. For this reason we have developed various techniques, changing with different steam superheating degree, and that make possible the economic utilization of the new fluid found .

Different technical solutions are applied, depending on where the dew point is formed according to thermodynamic conditions.

Very hot fluids do not bring corrosion problems in the casing and pipes, but only in certain stages of the turbine according to the expansion curve. To avoid this problem we have tested new materials able to resist corrosion. In this way it is also possible to remove the treatment of steam just before the turbine, which reduces the efficiency of cycle.

The new machine designed with the concepts of modularity has increased the efficiency of transformation and allowed to operate changes in a fast and flexible way, in order to follow the evolution of the reservoir.

We have also developed our monitoring capability with the development of sensors and signals transfer network. In this way we have increased our capacity of events prediction and elimination of false alarms, with an increase in the availability of the machinery.

The evolution of our ability to process signals has allowed to discriminate each small variation indicating a deterioration in operation (plant signature), in order to promptly operate both to reset the operation parameters on the values of maximum efficiency or to plan any maintenance action.

1. INTRODUCTION

The equipment's performance needs to be enhanced in order to increase the power generated from a geothermal source with a given amount of steam available.

Performance is generally understood to mean simply the conversion efficiency. However, here we want to examine all measures aimed at obtaining an ever-increasing number of kilowatt-hours from the available resource.

A first measure implemented was to adapt the equipment to make it possible to utilise fluids considered excessively corrosive. This allowed converting these fluids too into power generated. The steam washing section will describe the measures adopted and the equipment changes made.

A second approach is to work on the main equipment to reduce the decline of its efficiency resulting from its operation. Much work was done on materials. The use of materials more resistant to corrosion also made it possible to decrease the need for maintenance and to increase the equipment's availability. The section on the new materials used describes the measures implemented.

The equipment, utilised since the 1980s, is of the modular type. This provides a great deal of operational flexibility and allows adapting the installations to the evolution of the geothermal reservoirs. Being able to quickly adapt the equipment configurations to the evolution of the fields, during short shutdowns (possibly coinciding with maintenance shutdowns), makes it possible to keep the power plant constantly attuned to the reservoir's characteristics, in order to optimise the power generated. One of the most significant equipment changes has been to increase the length of the last blades of the turbine to reduce the losses in the form of kinetic energy at the turbine outlet. The section on turbine efficiency describes this modification.

It is crucial to be able to verify whether the power plant's components operate under conditions of maximum efficiency, in order to maximise the operation efficiency over time. The main operational parameters are affected by the environmental conditions; it is therefore very important to make them independent of season, in order to verify whether the equipment operates on its characteristic curves (plant signature. The section that discusses the operation control procedures describes the measures adopted to increase our ability to control and predict.

2. STEAM TREATMENT

Exploration for steam in the Larderello area is currently carried out at depths ranging from 3,000 to 4,000 metres. We have found that the chloride content in the steam increases with the depth of the wells. These chlorides concentrate in the areas where the first condensate drops are formed, thus making this condensate acidic. Corrosion problems, whose extent depends on the chlorides' concentration, arise in these areas. It is therefore crucial to control the superheated condition of the steam along the entire path from the bottom of the well to the turbine outlet.

In fact, the conditions that can lead the steam to the saturation curve are: cooling along the casing and surface piping or during the expansion in the turbine. This depends on the superheating conditions of the steam at the bottom of the well under delivery conditions. If the superheating is low, there is a very likely risk of condensation already in the casing where the fluid cools down, as it crosses cooler formations near the surface, and when this is not compensated by the pressure reduction due to pressure drop, which would tend to superheat the fluid. If, on the other hand, the fluid reaches the wellhead with an average superheating of at least 15-20 degrees (a condition that we find conservative to avoid local condensation points), the area at risk shifts along the steam pipeline where thermal dispersion (100—200 watt/m2) can generate points of condensation. The steam pipeline is insulated with insulating mats made of mineral wool. Under these conditions, it is very important to be able to check the performance of the insulation. In fact, condensation temperatures can occur on the steam pipeline's internal surface at the points where insulation is found to be deficient, even though the fluid's average temperature can suggest that safer conditions exist. If superheating temperatures of the order of 15 – 20 degrees still exist at the end of the steam pipeline and if the temperature checks along the pipeline exclude areas of deficient insulation, the critical area will certainly be the expansion stage in the turbine, where there is a transition from the superheated to the saturated zone.

Having defined the risk area, we shall now describe the equipment solutions developed to overcome, locally, the problem of corrosion due to the excessive acidity of the condensate.

2.1 Steam treatment inside wells

If the critical area is within the casing, it is necessary to neutralise the acidic condensation in this area. This is achieved by injecting water and an alkaline solution to neutralise the chlorides. We utilise an aqueous solution of sodium hydroxide. This solution is thus injected upstream of the area identified as critical, in the direction of the flow, through a pipe introduced inside the production well (see fig. 1-2-3).

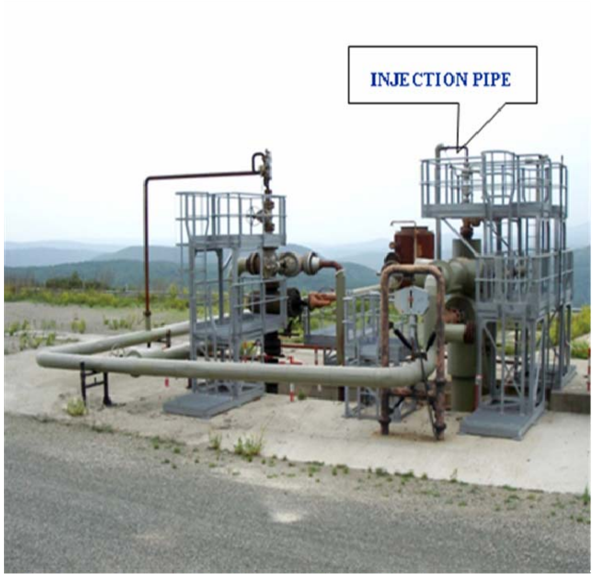

Figure 1: Steam treatment inside well.

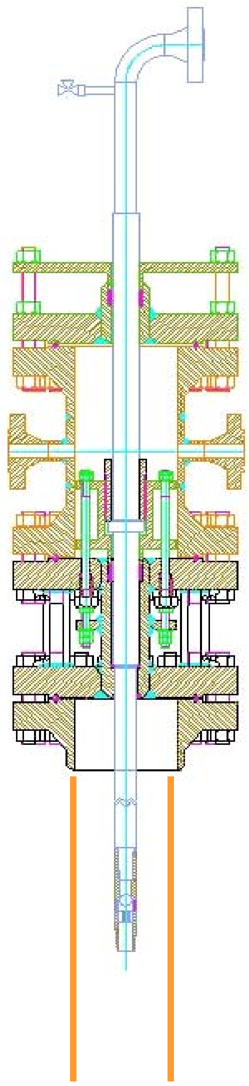

Figure 2: Steam treatment inside well: wellhead sealing system

Figure 3: Steam treatment inside well.

To do this, it is necessary to install a facility suitable to prepare the solution and to then inject it into the well, through a pipe suitably fastened to the wellhead (see fig. 4).

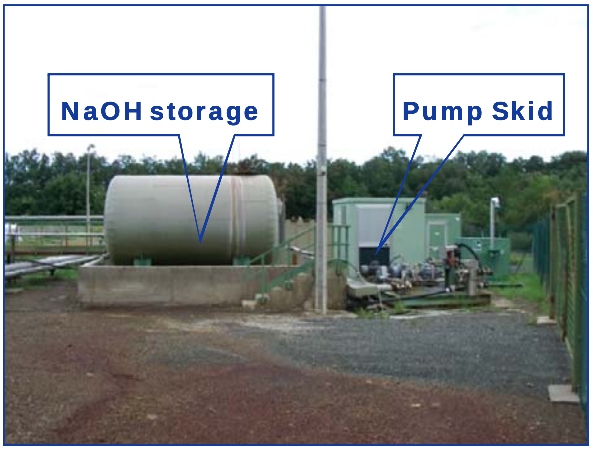

Figure 4: Steam treatment: plant for preparing the alkaline solution.

The mixing area is then the annular cross-section created between the casing and the pipe. The water is injected in quantities capable of bringing the fluid to saturation conditions, with a residual liquid phase so as to bring into solution the salts formed (sodium chloride) up to the wellhead. The amount of sodium hydroxide injected is calculated in slight excess of what is necessary to neutralise the chlorides present in the geothermal fluid.

2.2 Steam treatment at well head

If, on the other hand, the critical area is along the steam pipeline, it is more convenient to treat the fluid at the wellhead. The mixing and pumping installation is the same as in the case above and is still located at the wellhead (see fig. 5); the criteria for calculating the composition of the solution to be injected are the same as those illustrated above.

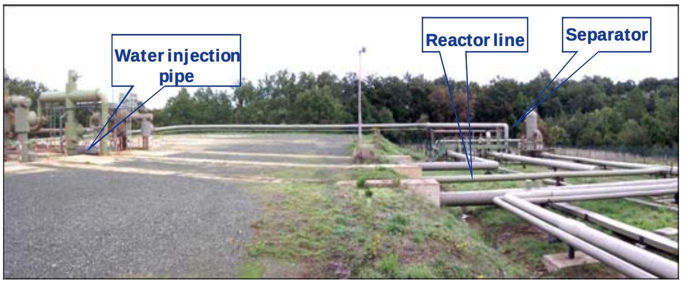

Figure 5: Steam treatment at well head.

The "reactor" is different: in the case above, it is a vertical pipe having an approximately annular cross-section (it is not known how much the pipe is concentric with the casing.) In this case, on the other hand, we have experimented with horizontal pipes (where a strong vortex is generated downstream of the solution's injection point) as well as with vertical reactors with structured packing. The first solution is simpler, but it is negatively affected by variations in the fluid's flow, as mixing relies on the turbulence of the flow; the second solution is more complicated, but more reliable in the cases of non-constant flows.

2.3 Steam treatment at the power plant

If, finally, the critical area is in the expansion phase in the turbine, it is necessary to treat the fluid before it enters the turbine (see fig. 6).

Figure 6: Steam treatment at the power plant.

The equipment is similar to that described for the treatment to protect the steam pipeline; the criteria for sizing the installation and the reactors are also similar to those described above.

2.4 Steam treatment: pros and cons

With this system, we are able to utilise fluids that are otherwise unmanageable, at least with standard materials. However, this treatment involves costs, in terms of both equipment complexity and consumption of materials (sodium hydroxide), but the main cost is due to the reduced energy efficiency. The treatment causes the loss of about 6% of the energy that the fluid would have without treatment. For this reason, over the past few years, we have experimented and developed the use of new materials which, although much more expensive, make it possible to avoid treating at least the fluids having chlorides contents up to 15 ppm. At the moment, it is inconceivable, for economic reasons, to change the materials of the casings and of the steam pipelines. What we did is to change the materials of the turbine blades, obviously when the fluid's characteristics were such that the fluid needed to be treated only upstream of the turbine. We are thus able to use these (not excessively corrosive) fluids, exploiting their enthalpy content without energy losses due to the neutralisation treatment. All this will be discussed in the following section.

3. NEW MATERIALS UTILISED

From the corrosion viewpoint, the most critical point of a geothermal turbine is the dew point area, where the steam starts condensing; if acidic chlorides (such as ammonium chloride or hydrochloric acid) are present in the steam, high concentrations and very acidic pHs are reached in this area. It is not easy to reproduce these conditions in the laboratory; for this reason, several testing campaigns on “real” fluids were conducted in the field, in order to verify the behaviour of the various materials considered to fabricate the blades of the geothermal turbines. The tests carried out in the field assessed the characteristics of the materials with regard to general corrosion, pitting, resistance to stress corrosion, and, in part to corrosion under deposit. We did not investigate two phenomena which, on the other hand, are found within geothermal turbines, namely corrosion-erosion and corrosion-fatigue, because of the difficulties in reproducing real-life conditions.

Various types of materials were compared during this test campaign: carbon steel and low-alloy steel; martensitic, ferritic, austenitic, and duplex stainless steels; super-austenitic stainless steels; a titanium alloy; and, for comparison, the X12Cr13 steel currently used to fabricate the blades. Overall, 34 different alloys were tested. It must be emphasised that the heat treatment, the purity and the mechanical characteristics of these materials have a significant effect on their corrosion resistance, on their susceptibility to stress corrosion and on pitting; this information was not always available when the test results were assessed. The materials tested were evaluated on the basis of their ability to withstand: general corrosion, pitting and crevice corrosion, and stress corrosion. An assessment was formulated for each condition to finally reach a summary matrix in which an overall assessment was assigned to each material; this assessment included the response to the four types of corrosion investigated: general, pitting, crevice, and stress.

Following this, real-life tests were carried out by constructing blades with materials other than the conventional material (X12Cr13.) Hastelloy C22 was chosen for the fixed blades and Inconel 725 for the mobile blades. The use of these materials made it possible to eliminate the washings in some power plants, thus recovering energy. The replacement of the blades with blades made of new materials is gradually being expanded, but this did not put an end to the tests to develop still better materials. The availability of materials increasingly resistant to attack by geothermal fluids is the fundamental step to increase the efficiency of the blades and to decrease the frequency of the maintenance interventions, which, besides involving a cost, decrease the availability of the equipment.

4. INCREASE OF THE CYCLE’S EFFICIENCY

Our power plants are of the modular type; this means that they are made up of components that, without needing to be redesigned, can be adapted to changes of the flows and of the thermodynamic characteristics of the geothermal fluid. This is a very important consideration in the geothermal field, because all geothermal reservoirs evolve naturally and the optimum exploitation conditions are not always at the same thermodynamic conditions. In addition this allows operators which, like EGP, have a significant number of installations, to optimise the management of the spare parts. Having modular plants means being able to change configuration by adding or removing components. Let us analyse the latest evolutions of the various components aimed at increasing their efficiency.

4.1 Turbine

A first activity was done on the steam sealing systems. The materials that were corroded by the geothermal fluid were changed. Corrosion modified their geometry and this increased the fluid’s losses to the condenser. The experiments performed on new materials also made it possible to change the materials of the turbine blades. This was a big quality leap, as it made it possible to convey to the turbine fluids with corrosion characteristics that previously would have required treatment, as described in the preceding sections. Eliminating the treatment made it possible to utilise these once unusable fluids, increases power production by about 6%, with the characteristics of our fluid. When the blades’ profiles retain their original geometry for longer times the conversion efficiencies also remain at optimum values for a longer time, thus postponing the need for maintenance actions. With regard to this, we want to recall that we tend to maintain the equipment by replacing the components and by making the repairs off-line, for example: replacement of the turbine rotor. This way, we are also able to decrease maintenance times, because we can replace much of the equipment with pre-configured parts, thanks to the equipment’s modular design.

An additional evolution took place in the design of the profiles of the last stages of the turbine (see fig 7).

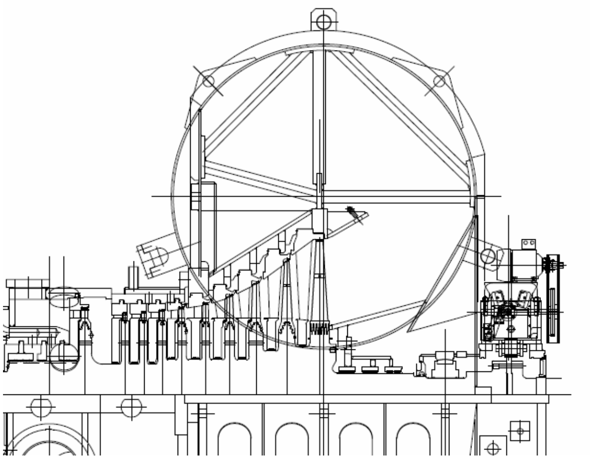

Figure 7: 20MW Ansaldo turbine

The height of the last blades was increased in order to decrease the losses in the turbine's discharge line. This way, a lower discharge velocity makes it possible to decrease the losses due to the kinetic energy not recovered at the discharge.

4.2 Gas extractor

The utilisation of gas extractors with multi-stage, single impellers with axial inlet (see fig. 8-9) made it possible to decrease the power drawn by this machine, which is necessary to maintain the vacuum at the condenser.

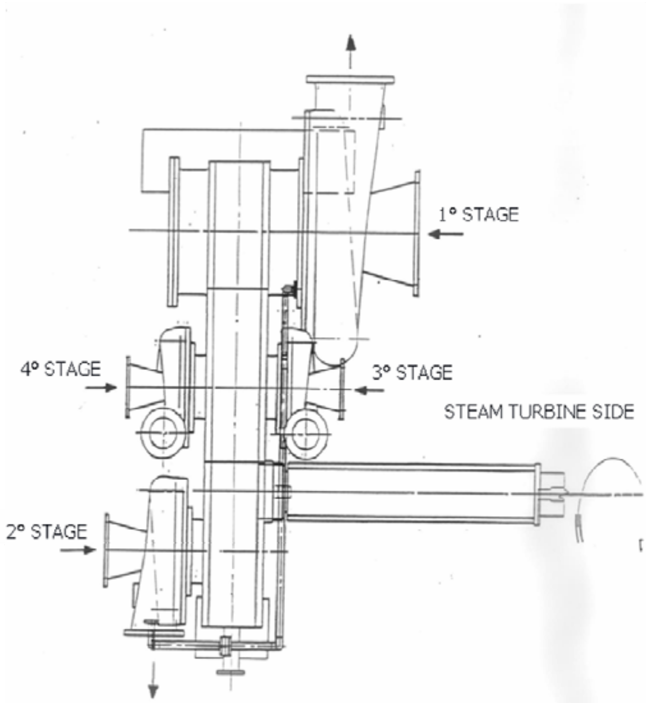

Figure 8: Gas extractor, plan view.

In general, there are four stages of compression with intermediate cooling. In this case, modularity consists in replacing the impellers, which must handle variable flows, but must have always the same head, which results from the difference between the pressure at the condenser and the atmospheric pressure, both of which are constant.

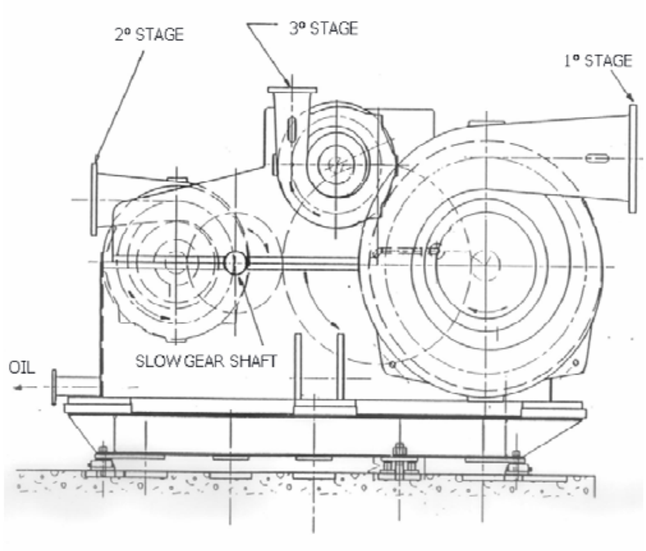

Figure 9: Gas extractor, view from steam turbine side.

5. DEVELOPMENT OF PREDICTIVE TECHNIQUES BASED ON DEVIATIONS FROM PROPER OPERATING MODES

Improving the average efficiency of a power plant requires that the plant operates always under optimum conditions and that the stoppages due to unplanned events are reduced to a minimum. The main operating parameters generally utilized as indicators of efficiency, such as net power generated, vacuum at the condenser, and cold water temperature, are not constant at equal efficiency of the equipment, because they are affected by the weather conditions. In the case of wet tower power plants, like ours, the air's wet bulb temperature affects the temperature of the cold water entering the condenser, which, in turn, affects the vacuum in the condenser and, therefore (by changing the turbine's operating conditions), the net power generated in the plant. Therefore, it has become essential to make the operating parameters independent of the weather in order to understand whether we depart from the optimum operating mode or not, under given environmental conditions. To this end, we have developed a set of algorithms that report the values at standard conditions in order to then make a comparison. The need to prevent all events that could lead to an operational drift made it necessary to control not only the main operating parameters, but also the characteristic values of operation of the individual machines, distinguishing the parameters that must be made independent of the weather from those which must be treated as values depending exclusively on the machine. In this regard, since the operating conditions of the machines are inevitably different, we have developed a signals processing system such that an absolute criterion is not applied to determine the acceptability of the values, but only if the deviation relative to the values specific to that machine exceeds a pre-determined value. We have therefore characterized the operation specific to each plant, which we call "plant signature"(see fig. 10-11).

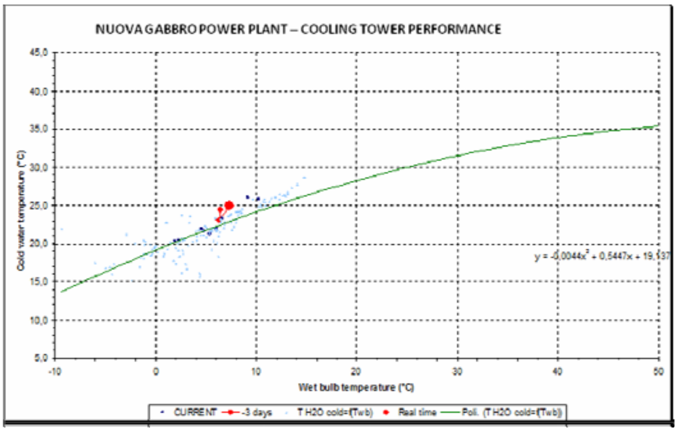

Figure 10: Plant signature, a good operation example: cooling tower working points (red points) compared to the tower plant signature (green curve).

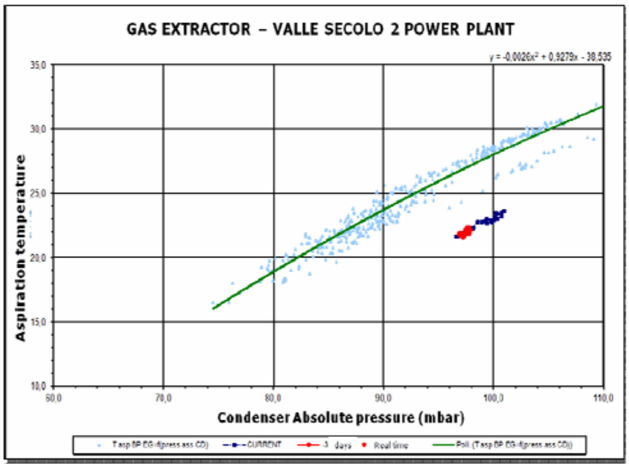

Figure 11: Plant signature, a deviation from good operating line: gas extractor operation points (red points) compared to the plant signature (green curve).

The deviation from this characteristic is the parameter that indicates the need for additional checks. To make a medical analogy, we could say that each plant has its own electrocardiogram; we check its deviation from the initial electrocardiogram. More generally, we could say that we have constructed, in a multi-dimensional space, which is a function of the independent variables that govern the operation of a piece of equipment, the locus of the points of correct operation. In the event that the actual operation departs from this locus beyond a preset value, the system automatically generates a signal. In addition, rules correlating the combinations of variations of certain operating parameters to ensuing events having the potential to cause accidents have been established on the basis of operational experience. Similarly, messages that may indicate a malfunction are also generated, and can be processed by the operators (see fig.12).

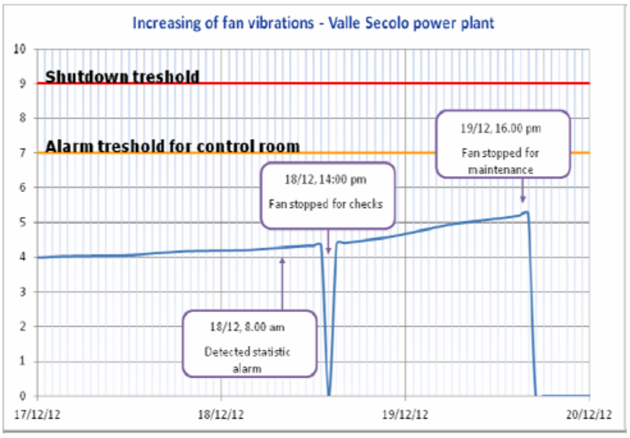

Figure 12: statistic alarm example: increasing of fan vibrations in Valle Secolo power plant. The maintenance intervention was planned before the alarm to the control room was generated.

This way, we can be warned at the moment there is any change (even extremely small) in the mode of operation of each individual piece of machinery.

In fact, an incipient deterioration can be associated to each change. In this regard, we recall that all our plants (35 generating groups) are controlled from a remote control station and that no continuous supervision is therefore present at the plants. The availability of effective predictive tools allows us to schedule the checks sufficiently in advance of reaching the conditions of risky operation.

Up to now, this has been made possible by the technological efforts of the past ten years; in fact a broadband network connecting all 35 installations and the remote control centre was completed during this period and the plants' SCADA [Control and Data Acquisition Systems] have been adapted; this makes it possible to construct, in real time, a complete and centralised database of all the signals and measurements generated by the peripheral installations.

Establishing this type of database was the starting point for the development of a number of applications that have been added to the typical remote control functions; today, we have remote supervision functions, such as the return to remote control of the operating data, or more advanced remote diagnosis functions, such as those to evaluate the efficiency of the performance or others, that make it possible to interpret the RCE data semi-automatically or that provide prediction-type indicators on the conditions of the equipment. Specifically, with regard to the RCE [Chronological Event Recorder] function, it is possible to discriminate the so-called "first out," that is the first cause of the fault that occurred. It is also possible to export the record, which can be utilised to compare it to other similar earlier situations, to verify the correct behaviour of all components.

The platform on which these functionalities were developed makes it possible to continue generating new parameters, calculated through logic and mathematical algorithms, which also derive from operating experience; this provides further opportunities for the operators to prevent outages, by scheduling targeted maintenance activities.

The system also makes it possible to personalise the form of interface with the operator; this means that it is possible to access the information through personalised screens, but also to create alarms and signals to be delivered to the operator through email messages or simples conditional SMS. This way, our technicians and operators can also be warned selectively, depending on their competencies.

The activity of the Remote Control Station's operators has also been affected by the introduction of these remote diagnostics systems, greatly enhancing the ability to discriminate the type of fault or event, and thus making it possible to provide more information to the persons called to intervene. Alternatively, it also provides greater opportunities to defer the activity while keeping under observation the evolution of the phenomenon under way.

6. CONCLUSIONS

Continuous improvement is what drives our activity. We want to be able to transform in energy all the fluid that we find, to operate the plant at the maximum efficiency and to increase operation flexibility. This is the basis for the development of control and prediction techniques, to which the analysis of recurring faults are linked; the goal is to implement measures that ensure that the fault event does not reoccur.

Through the years, all these integrated activities have made it possible to maintain a trend of decreasing the number of outages in the production plants with a corresponding decrease in the rate of accidental unavailability (see fig.13). This performance indicator is calculated considering the ratio between the real production and the production equivalent to a full load full time. In this way the "accidental unavailable capacity" of a geothermal production group is due either to unplanned stop, and to another condition that involves a capacity reduction of the plant (less production compared to the maximum possible with that environmental condition) .

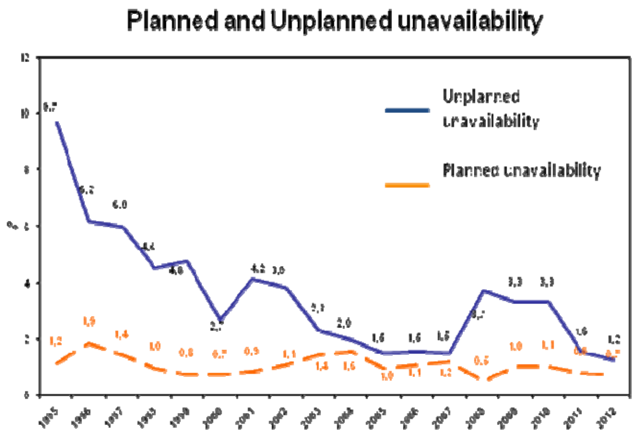

Figure 13: Planned and unplanned unavailability trend from 1995 to 2012.

The real challenge that we face now is to maintain or improve these excellent results, in order to maintain the high level of operational excellence in the geothermal plants.

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