Optimising the Multiple Purpose Function of the Socorridos Hydro Power Station for Use All Year Round to Produce Water for Public Supply, Irrigation and Electricity

**Key words:** Renewable energies, Energy efficiency, Water collection and supply

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<th>Region:</th>
<th>Autonomous Region of Madeira, Portugal</th>
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<tbody>
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<td>Programme type:</td>
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<td>Duration of project:</td>
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This project concerns optimisation of the Socorridos Hydroelectric Power Station in use since 1995. It is the largest and most important hydraulic system for production of water for public supply, irrigation and hydro energy in Madeira. The project represents an important step forward in the process of taking advantage of renewable energy sources, particularly of eolic origin.

Equipped with three generator groups of 8 MW, this power station provides maximum power of 24 MW. The system includes a 15.5 km long succession of tunnels (underground canals) and canals (open air) as well as a hydroelectric power station. The joint coordination of these infrastructures makes it possible to transfer water collected in the northern part of the island (higher and mountainous where it rains) to the southern part of the island. The water is used for irrigation, public supply of water and energy production.

However, as the capacity of the primitive loading chamber was limited to a maximum 7,500 m³, which was not enough water, its production of electricity and guaranteed power occurred essentially during the rainy season (winter).

The Empresa de Electricidade da Madeira (EEM, the public electricity company of Madeira) carried out the project which transformed the Socorridos Hydroelectric Power Station into a reversible system, making it possible to take advantage of its power capacity at any time of the year, regardless of rainfall.

The project consisted of 4 main parts:

- Construction of the Covão tunnel
- Construction of the Socorridos storage gallery/reservoir
- Renovation of the Encumeada and Canal do Norte tunnels
- A pumping station at Socorridos
Together these elements ensured that more water was available for irrigation and public supply. Moreover, energy production all year round and also during the day at peak periods was guaranteed. Water was pumped back to reservoirs so that it could be reused for electricity production. By reusing the water, electricity production could be ensured all year round. The pumps are driven during the night, storing the water for use during peak hours during the daytime. Additionally, the pumps can be connected and then can make increased use of wind power, thus producing more renewable energy during the night. This initiative, as part of the Socorridos Multiple Purpose Utilization Project, represented not only a significant investment in the management of the regional hydroelectric resources but also an important step forward in the process of taking advantage of renewable energy sources, particularly of eolic origin.

One of the objectives of the regional strategy of the Autonomous Region of Madeira is that of sustainable development, facilitating the promotion of social and economic wellbeing with the protection of the natural resources that sustain quality of life. Within the scope of this objective, the environmental dimension entails a strategic priority. The investment in this project, with low environmental impact, had the clear aim of contributing towards development of the Madeiran economy, giving it more and better energy, in other words, sustainable development.

### I. PROJECT DESCRIPTION

**Project objectives**

Security of energy supply, protection of the environment and economic competitiveness are the strategic goals for the energy sector. In addition to these, Madeira is working towards cleaner and more renewable energies in the regional market via the improvement of feasible and efficient alternatives to sources of energy from oil.

Based on the above, the key objective was to ensure that the Socorridos Hydroelectric power station (operational since 1995) could be used to produce electricity all year round, including at peak periods, as opposed to only during winter periods when there is enough water. The other objective was to increase the amount of water available for irrigation and its delivery as well as water for public supply. The project worked by making the best and most efficient use of water resources for the supply, irrigation and production of electricity.

The objectives of the project were:

The production of energy:
- guarantee that 24 MW of power and 44 MWh are available daily;
- cut energy losses estimated at 2.54 GWh per year;
- introduce additional wind power estimated at 12 MW;
- improve the management of hydroelectric resources.

Public supply of water and irrigation:
- increase reliability of the water supply system to the cities of Funchal (Water Treatment Station at Sta Quitéria) and Câmara de Lobos (Water Treatment Station at Covão);
– deliver 65% of irrigation water to the distribution facilities at Covão and Campanário, minimising estimated losses by some 1 300 m³/day in the Canal do Norte (southern section) between the Serra de Água power station and Campanário.
Description/type of activity

Funding was used to carry out work to improve the public water supply and irrigation, and also guarantee electrical power and the production of electrical energy related to Socorridos hydroelectric power station. Had these works not been carried out, the other option would have been to burn more fossil fuels instead. This was quite a major engineering feat on an island of this size.

The project consisted of four main stages:

- construction of the Covão tunnel;
- construction of the Socorridos storage gallery/reservoir;
- renovation of the Encumeada and Canal do Norte tunnels;
- pumping station at Socorridos.

Construction of the Covão tunnel
This was a 5,243m extension with 3m-diameter tunnel connecting Covão and Campanário. The tunnel can hold 32,500m³ of water and supply water for irrigation at Covão and Campanário. This tunnel fulfils two main objectives: to supply water for irrigation on both sides of the tunnel, thereby reducing losses; and provide storage in order to ensure a reliable water supply and electricity production.

Construction of the Socorridos storage gallery/reservoir
This involved the construction of an underground reservoir which can store 40,000 m³ of water and the facility housing the pumping equipment.

Renovation of the Encumeada and Canal do Norte tunnels
This renovation included structural consolidation of the Encumeada and Canal do Norte tunnels as well as installation of gates to regulate the flow of water, allowing the storage of up to 55,000m³ of water. The gates enable some water to be sent to the water treatment station for public supply and some to be supplied for irrigation. Independent of this, water for energy production can be sent to Socorridos.

Pumping station at Socorridos
The pumping system uses 3+1 pumps of 3.7 MW, 0.65 m³ s⁻¹ (each), with a peak of 457m, and all electro-mechanical equipment necessary for its operation.
The parts work together as follows:

Water collected from the mountains flows into the system. Previously, in the summer all collected water was used for consumption (public and irrigation), leaving no water available to produce hydro energy. The project was designed so that it could use water for electricity without restricting the amount available for daily consumption needs.

During the day, water stored in the Socorridos multipurpose system (Encumeada (1), Canal do Norte (2) and Covão (3) tunnels) can be used to produce electricity through turbination of the water to drive generators at two power stations along the way at Sta Quitéria (4) and Socorridos (5).

At Sta Quitéria, all water is used for public supply after turbination. At Covão, some water is diverted for irrigation and also to water treatment plants for public supply. At Campánario (6) too, some of the water is diverted for irrigation.

All water passing through turbination during peak periods at Socorridos hydroelectric power station (5) is stored in the Socorridos storage gallery/reservoir (7). At night water is pumped back (8) up the Covão tunnel (3) so that it can be used again the next day, completing the cycle.
The project enabled an increase in water capacity available for the following uses:

- utilisation of the system to produce electricity without the constraints of needing sufficient water for public supply or irrigation, thus also increasing the capacity of water for irrigation and public supply;
- guaranteeing the availability of electric power, even during periods when there is no rainfall water (summertime) for that purpose;
- cutting the use of fossil fuels (additional production at Socorridos and Fajã dos Padres power stations, enhanced efficiency at Vitória power plant, and extra wind power introduced);
- improving overall efficiency/capacity and more flexible management of electricity production and water distribution systems.

This initiative, as well as making it possible to improve public supply and irrigation along the southern section of the Canal do Norte, also made it possible to transform the Socorridos hydroelectric power station – a winter power station particularly dependent on rainfall – into a reversible power station which can be used throughout the year.
Beneficiaries

The inhabitants of the island are ultimately the beneficiaries of cleaner energy as well as more efficient irrigation and public water supply. The environment also benefits.

II. POLITICAL AND STRATEGIC CONTEXT

Strategic context

The Regional Energy Policy Plan (PPERAM) targets a decrease in fossil fuels through the use of renewable energy, pursuant to EU directives, in order to minimise the environmental impact. The region is currently using about 80% fossil fuels, 2% wind, 4% waste incineration and 10 to 15% hydroelectric energy, depending on the hydrologic regime. The primary goal for future electrical energy production is to obtain about 30% from renewable sources and the use of thermal sources with less impact on the environment, namely LNG (liquid natural gas) as a substitute for heavy fuel oil. To achieve the 30% renewable energy target, the Region, owing to the specific conditions found on the island (isolated network with no outside connection), is having to build some key infrastructures. This project’s philosophy fits in with the idea of assisting the improved exploitation of hydroelectric resources and the integration of more wind power.

Tourism is one of the main economic sectors on Madeira, representing about €250 million with 900,000 tourists visiting each year who stay for an average of 6.5 days (2005 data). Improving the region’s energy and water supply is vital in order to face the growing needs of both.

Agriculture: The main levadas (small irrigation canals) were built in the 1940-1950s to provide irrigation and hydroelectricity. A typical tourist activity involves walking along the levadas. The project was designed to operate without interfering with the irrigation and water consumption systems, and to guarantee reduced losses of water and new irrigation delivery points. This is vital for maintaining farmland, making an important contribution to regional agriculture and tourism.

Innovation

New technology

Traditionally, reversible systems are applied on big stream flows and small elevations using Francis turbines. In Madeira, there is only one type of turbine used (the Pelton turbine) due to the large drop in altitude. Since the direct use of reversible turbines in relation to the existing fall in height and the range of power were inadequate, EEM chose an autonomous pumping system, designed for the same drops in height, but using the same hydraulic infrastructure (penstock and intake/discharge chambers). This constituted an innovation in the approach to hydraulic systems for major falls in height. This way of thinking can be applied to all hydraulic systems, regardless of the equipment used.

For the first time in the Autonomous Region of Madeira, a tunnel boring machine (TBM) was used to dig a tunnel with a diameter of 3m running for 5,243m between Covão and Campanário. This was completed quickly with little environmental impact.
The entire reversible system, from its conception and working principles to the unusual characteristics of the pumps used, reflects the project’s innovative character.

Combination of two types of renewable energy:
Equally as innovative, the strategy used (pumps and water/energy storage) made it possible to connect additional wind power running all year round, thus increasing the proportion of renewable energy. At the same time, the project optimised hydroelectric production in wintertime. In summertime, the project guaranteed power and energy, deferring investments in thermal power.

Political support

The electricity company is 100% owned by the Government of Madeira, which provided all co-financing for the project. The Government, through the offices of the Vice-Presidency, made several visits to the project during construction, raising the profile of the project on TV, radio, and in newspapers and magazines. The project was inaugurated in March 2007 when a video was presented showing the project's objectives, components, working plan and construction details. EEM published a special supplement detailing the project in the Diário de Notícias and Jornal da Madeira newspapers. The project was chosen by the managing body for presentation to Commissioner Danuta Hübner during her visit to the Region in October 2007.

III. IMPLEMENTATION

Programming

The Regional Energy Policy Plan (PPERAM) targets a decrease in fossil fuels through the use of renewable energy, pursuant to EU directives, in order to minimise the environmental impact. This is of great importance to a region like Madeira so reliant on tourists. The project fitted in well with the Regional Energy Plan since it optimised the use of renewable energy, particularly with respect to wind energy, as a substitute for the use of fossil fuels or investment in thermal equipment.

Within this framework, EEM (the electricity company) developed Madeira’s largest and most significant multi-purpose hydraulic enterprise for the public supply of water and also water for irrigation and energy between 1991 and 1997. This system was formed by 15.5 km of tunnels and canals, some in the open air, and a central hydroelectric facility boasting three sets of 8MW generators. At this stage, storage (upper reservoir) was limited to a capacity of 7,500 m³ usable for the production of electricity and to guarantee power. This meant that it could only be used during the rainy season.

Due to the need for energy to cover peak periods throughout the whole year, EEM then developed the idea of a reversible system so that stored water could be reused. The first step was the design of the project, followed by a study to show feasibility and how it would fit in with the Regional Energy Policy Plan. In the process, three options were considered internally to see how best to meet high peak usage: diesel generators, gas turbines, and conversion of the hydro power plant at Socorridos for reversible operations. Taking into account the added value for the public water system (consumption and irrigation), the benefits in terms of electricity and the best fit with PPERAM, Socorridos was chosen.
2001   Design/layout of the project
2002   Opening technical and economic feasibility study, carried out internally
2003   Publication of calls for tenders
2004   Economic feasibility study, carried out externally
2004-2006   Actual building work
2007   Administrative work and financial completion of the project

Management structure quality and effectiveness

This project was divided into four subprojects (Covão tunnel, Socorridos storage gallery/reservoir, Encumeada and Canal do Norte tunnels, pumping station at Socorridos), each with its own project management group. The overall project manager responsible for all projects was EEM, which supervised the four separate projects through different coordination teams. Within the project’s management structure there were five joint departments working on all four subprojects. External assessors also examined geological/geotechnical and health and safety issues.

Since the project involved the public water supply and irrigation, which are services under the authority of the public water companies (IGA: Investimentos e Gestão da Água; DSH: Direcção de Serviços Hidroagrícolas), implementation of the project (project design/layout) took place in cooperation with those partners.

Partnership

The project involved the Regional Government as single shareholder in EEM (the electricity company acting as project manager and which developed the entire project) along with two other regional bodies in charge of water management (IGA and DSH), both 100% owned by the region.

The companies involved were either engineering companies (Planege, Cenorgeo, Tetraplano, Proceol, Siemens/Halberg/Sterling) or construction companies (Spie Batignolles Europe, Construtora do Tâmega, AFA, Energetus). The Centro de Estudos de Hidrossistemas (IST: Technical Institute of Lisbon) undertook hydraulic transient analysis of penstocks and factored in adequate safeguards.

Marketing

It was decided to split the project into four parts due to the range of expertise required and the different work locations (i.e. tunnels and canals). Four calls for tender were then published: three national, and one international.

The project was shown on television, radio and featured in newspapers during the construction and at its inauguration. School visits were organised for children so that they could learn about both the project and renewable energy. Several parties of university students and members of the European Parliament also toured the project. The project has been presented at a dozen or so international scientific conferences.
Difficulties in terms of design or implementation

**Timing**: there was a short timeframe from design to project execution, due to the need to have the system up and running quickly (electricity peak). The hydroelectric power plant at Socorridos needed to be finished by December 2005 and the pumping system operational by summer 2006.

**Cooperation**: executing the project without affecting the normal water supply (public consumption and irrigation) was always a big challenge.

**Funding**: there was some difficulty with proving the project’s feasibility. At the beginning, EEM was unsure about finding the right equipment (owing to its highly unusual specifications) and how much it would cost.

**Knowledge**: there was a need for a specific design for each specific case, particularly in the case of the pumping station house and the pump’s hydraulic system.

**Transferability**
Regions that already have a small-scale hydroelectric power station and wishing to make use of this system would only need an additional reservoir to collect the water (instead of allowing water to be discharged into a river or the sea) and pumps. By pumping and storing during a low-usage period when energy is cheap, the electricity can then be sold for profit during a high-usage period. The Technical Institute of Lisbon collaborated in the project, as stated earlier, thus allowing its students to acquire practical learning experiences about the technology used. The EEM electricity company would be delighted to assist any other interested regions.

**IV. EFFECTIVENESS**

**Effectiveness**

The objectives on the whole have been met. In addition, the project has achieved greater use of wind energy that would otherwise not have come about.

- **Significant additional flexibility has been attained in the exploitation of hydroelectric resources in particular and in production facilities generally.**

  The water storage capacity in the tunnel at Covão is equivalent in energy terms to 44MWh, which can be turbinated during peak hours and pumped during the night, in accordance with needs. As an example, the energy capacity stored (44 MWh) can be used over two hours at 22 MW of power or at 4.4MW of power for 10 hours.

  A decrease in energy losses estimated at 2.54 GWh per year has been achieved and distributed as follows:

  - Socorridos power station – 0.64 GWh: additional energy produced during the transition from wet to dry seasons. This is energy that would have been "lost" if this new storage capacity had not been developed;

  - Fajã dos Padres power station – 1.78 GWh: this additional energy results from water delivery at Campanário, via a small canal, which would otherwise have been lost;

  - Vitória thermic power station – 0.12 GWh: resulting from better thermal efficiency due to better management of the hydro system.
- **Increased reliability of the water supply system**
  The current storage of 95,000 m³ (40+55) of water instead of 7,500 m³, as was previously the case, has enabled additional use of water for contingency situations. It has also increased the reliability of the supply of water to the capital and Câmara de Lobos.

- **Increase in the amount of water available for irrigation and enhancement of its supply**
  Supplying water for irrigation at the distribution facilities in Covão and Campanário has reduced the volume of water distributed at the Serra de Água power station and, as a consequence, cut losses along the irrigation canal (estimated at 1,300 m³ per day). Construction of the Covão tunnel enabled an additional alternative to be used for water supply for irrigation (previously, part of the canal had been unreliable and often subject, during wintertime, to falling stones, blocking the flow of water).

- **Increase in the introduction of wind generators**
  The intake of wind power is estimated at 12MW. This equates to average energy power of 44 MWh, equivalent to storage/retention of 40,000 m³ of water in the tunnel at Covão, during non-peak hours. Based on this assumption, wind power will be strengthened. Currently, the contribution of the wind systems installed (8.64 MW) is about 2% of total energy consumption, with an average value of 16 GWh. Thus, additional average annual production approaching 24 GWh is expected from the new wind generators. These additional 24 GWh of wind-generated electricity eliminate 16 750 tonnes of CO₂ each year. EEM has decided to add additional wind power of about 25 MW in the coming years. Recently, a contract was signed for the introduction of 15 MW of wind generators by 2009.

**Impact**

One of the objectives of the regional strategy of the Autonomous Region of Madeira is sustainable development, reconciling the promotion of social and economic well-being with the protection of natural resources which sustain the quality of life and the advancement of the island’s population. Within the scope of this objective, the environmental dimension becomes a strategic priority. Investment in this project, with its low environmental impact, had the specific aim of contributing towards the development of Madeira’s economy and giving it more and better energy; in other words, sustainable development.

Tourism is the main sector in Madeira and the majority of tourists come for the scenery and walking holidays along the irrigation canals. It was therefore also important to work to build the system in a way that was not intrusive to the environment. The project still directs some irrigation water into the levadas so that small farms and families can continue their activities, thus providing a scenic backdrop for tourists walking along these small canals.

Due to the success of the Socorridos station, the region will be starting work to convert the hydropower station at Calheta, which is much bigger than the Socorridos power station, into a reversible system. This is expected to be ready in 2010. The impact of this investment is similar to the project at Socorridos, but on a larger scale since the water storage capacity at Paúl da Serra will be approximately 1,000,000 m³.

The result for the Region, of course, is more water available for irrigation and public supply as well as a higher percentage of renewable energy. It also enables the Region, by virtue of storing energy that otherwise would be lost during low usage periods (through water storage),
to be used at peak hours when demand is higher. Inclusion of the new, reversible form of hydroelectric potential made it necessary to develop a new strategy in terms of the exploitation of production facilities. At present, having the power made available from the Socorridos hydro system available at any time of the day provides additional flexibility in terms of exploitation. In terms of public supply and irrigation, this measure has made it possible to create an alternative to the existing system, increasing its reliability and reducing losses.

There is no direct impact on the electricity price for the consumer due to the fact that Portugal has a fixed, regulated national tariff for electricity.

**Sustainability**

This project is expected to be maintained throughout its entire operating life (30 years for the equipment, 50 years for the hydraulic infrastructures). There are no plans for any changes over the period mentioned above.

The new technical components introduced under this project, namely the pumping equipment/stations for major drops in height, make it possible to reproduce the concept in other projects offering higher potential to contribute to maximising the use of renewable energy. For Madeira, one of the limitations in benefiting from renewable energy is the difficulty of integrating all renewable energy supplies within the network, especially during the periods of heavy rain in wintertime. This led to the idea of replicating the Socorridos concept as part of another project, "Remodelação do Aproveitamento Hidroeléctrico da Calheta", with a much higher capacity than Socorridos, in order to increase the use of renewable energy. An upstream capacity of 1,000,000 m³ and downstream of about 60,000 m³ will allow major flexibility in the management of water to be turbined/pumped into the Calheta hydro system, which will reinforce the capacity to absorb/use renewable energy and guarantee coverage during peak periods in contingency situations without affecting the normal supply of water for the public and irrigation.

### V. CONCLUSIONS

**Lessons learnt**

Faced with a project featuring such innovative aspects, EEM had to be pioneering in terms of both new technology and specific know-how. The management structure, with its different coordination teams and competences, was vital in order to resolve problems during the project, adding further to the success of its implementation. Additionally, support from external assessors, who provided help on specific elements, was important. EEM has learned the following lessons for future similar projects:

**Commitment and cooperation:** it is very important to ensure the involvement of and support from main actors/entities throughout the project; keep up-to-date about possible interference with other entities and obtain compromises in order to maintain effective coordination of all elements involved.
Knowledge and the right people: knowledge must be deployed in the right place, internally and externally, and people assigned according to their specialities, experiences and know-how.

Planning and timing: sound planning is fundamental. Any mismatch in coordination at any stage of the project may result in serious problems with damaging consequences for the project as a whole. Possible interference must be anticipated at every stage of the project, in order to avoid constraints within the overall planning that could delay or postpone the project.

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