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WATER AND SANITATION FOR ALL: PARTNERSHIPS AND INNOVATIONS

Postwar village hydro-power rehabilitation

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CAMBINE IS AN institutional centre with a secondary school for 1000 students, boarding facilities for 200 students, a bible school, a 35 bed health centre and residences for a population of 500. During the 17 year long armed struggle following independence from Portugal in 1975, Cambine suffered destruction of buildings and infrastructure.

Cambine's water and energy resources were provided by a stream which is fed by a natural spring. In the 1920's, a small dam and hydro-power facility were built. The turbine provided mechanical power for a sawmill, a grain mill, a water pump that supplied a piped water system and a small electrical generator. A diesel generator was also located at the dam site to meet the electrical energy demand at night. In 1987, the power house was dynamited in an attack, destroying the facility and severely damaging the masonry dam. The loss of pride and stability that the people felt was significant.

A 30 KW diesel generator was installed after the war for providing electrical energy. This generator was large enough to meet the electrical demand of Cambine. The operation and maintenance cost was $3.50 USD per hour. With an average salary of only $1 per day, the population could only afford to run it two hours per day. Extending the distribution grid to more customers could have lowered individual rates and extended operating hours, but the high cost of extending this grid to a sufficient number of customers in a rural area prohibited this.

Two drilled wells were installed after the war, one equipped with a hand pump and the other with an electric pump. The electric pump supplied a water tank for the piped water system. The existing aged galvanized piping was replaced with PVC piping. The previous system had pumped river water through a sand filter before feeding it into the water tank. By using well water, the filter was no longer needed.

The piped water demand for Cambine was calculated at 24,000 litres per day. Only human consumption was included in this calculation since water for other uses could be obtained directly from the stream. The output of the well was only 2,000 litres per hour. The electricity for this pump was supplied by the diesel powered generator, which only operated two hours per evening, therefore the water demand was not being met. Although the hand pump could supply the water needs of the population, the health centre and the large student population dictated the need for a piped water supply.

A more economical energy source was required to supplement the diesel generator-supplied electricity. Twelve hours of electricity per day were required to run the water well pump. The health centre required night lighting and sufficient hours for refrigeration and sterilization equipment. The school needed lighting for night classes.

Feasibility studies of alternatives

Feasibility studies were performed for systems that would meet both the energy and the water demand. The assumption was that the diesel generator would continue to be operated two hours per day for the evening lighting load. Costs were calculated above that of still running the generator, except for the alternative of the extension of the government grid which would eliminate the need for the generator. Comparative costs were made of the initial capital costs, the net present values, the annual cost, the unit energy cost, the operating and maintenance costs (O+M) and revenues. Calculations were made assuming a 20 year project life and a discount rate of 1 per cent.

Table 1. Comparative costs of electrical energy sources

A development grant of US $20,000 was available for this project. Because of this, the decisive factors were the initial capital cost, the unit energy cost, and the annual O+M costs and revenue.

The alternative with the lowest initial capital cost would have been to run the existing diesel generator for an additional two hours each night. An additional well at a cost of $10,000 was the only initial cost needed to provide a sufficient water supply. As stated earlier, the unit energy cost of $0.23/kwh and annual O+M cost of $2,500 was prohibitive.

Extension of the government grid from the nearest town 12 kilometres away was considered as an alternative in order to purchase electricity at the rate of $0.07/kwh. This would have helped the development of the surrounding population of 15,000 people. Because this government grid was supplied with only 4 hours of diesel generated power each night, an additional water well was also included in the initial cost. The initial capital cost of $47,000 was prohibitive.

Solar energy would have provided an acceptable alternative at an initial cost of $16,500. Included in this cost was a solar operated water pump installed for $9,500. This battery-less system would only pump 12,000 litres per day by solar power and an additional 4000 litres per day by generator power. Although this did not meet the calculated demand, water conservation measures would have made this acceptable. The health centre and the two night schools would each have their own collection and battery storage system. The system for the health centre included a small 12 volt refrigerator for immunization storage. The annual O+M cost consisted of the purchase of new batteries with a life time of 4 years. This O+M cost at $425/year was the lowest of all the alternatives. The big attraction of this alternative was the speed and ease of installing the system and the simplicity of its operation.

Initial survey of the damage to the hydro-power plant led to the conclusion that it could not be repaired. The alternative of a new dam, turbine and generator had an initial cost of $42,000. The unit energy cost of $0.15/kwh was attractive, but the initial cost was prohibitive. Further study revealed that the dam could be repaired. The inexpensive price of labour relative to the price of material ($1/day labour vs $10/sac of cement) brought this option down to $29,000. Again, with the inexpensive price of labour, $10,000 could be saved by repairing the existing water turbine instead of purchasing and importing a new one, bringing the initial cost down to $19,000. The energy met all the night lighting requirements for the health centre and schools and the water pumping demand. The 24 hour per day energy could be used to produce income when energy was not being used for lighting and pumping. This income was calculated at $2,200 per year. With an O+M cost of $800 this alternative produced an annual revenue of $1,400. This revenue could be used to run the diesel generator for an additional hour each night to provide all of Cambine with electricity. The building of the hydro-electric facility was therefore chosen as the most appropriate energy source.

Figure 1. Daily electrical demand/supply

Rehabilitation of the hydro-electric facility

Hydro-potential

The stream is fed by natural springs 600 meters upstream from the dam which provide an almost constant year-round flow. The population has been educated in the importance of protecting this flow. The local authorities organized workdays to protect the spring and the river basin from erosion and restricted land use in this area. The hydro potential is provided by a 4 meter head created by the dam and a run-of-the-river design flow of 110 litres per second. The gross power of 4.3 kw provides a net power of 3.5 kw available from a turbine operating at 80 per cent efficiency. The estimated electrical output using an induction generator at 90 per cent efficiency is 3.0 kw.

The economic viability lay in maximizing the plant factor, the percent of energy used from this 24 hour per day energy source. Full energy output would be used in the evening hours for fluorescent lighting of the health centre and the night school. Twelve hours would be used for running the water pump. Two hours would be used for sterilization at the health centre. A low plant factor resulted with only this use, but the unit energy cost of $0.11/kwh would have been acceptable.

Prior experience proved there was a market for battery charging for home energy use and a market for chilled beverages to the surrounding population. Refrigerators could be run at the same time as the water pump. Battery charging could be done during a six hour day period. A plant factor of 83 per cent could be achieved resulting in a unit energy cost of -$0.02/kwh. Two thousand dollars were included in the initial cost for the purchase of refrigerators and battery chargers. Since the Cambine administration was capable of managing and maintaining the current water and electrical utilities and of revenue collection from the users, this additional enterprise was also within its capability.

Dam reconstruction

The subsoil profile of the 35 meter long dam site was very irregular. One half of the natural stone masonry dam was built directly on weathered limestone, the other on a permeable base of gravel and sandy silt. The depth of this layer was over two meters and could not be measured. Compacted sandy silt had been placed against the upstream face of the dam to slow water penetration through the permeable base. The explosion had created a structural crack at the point where the foundation changed from resting on bedrock to resting on soil. This crack appeared to have initiated the piping of water which in time resulted in the catastrophic undercutting of the dam. Over the years, two large fig trees grew adjacent to the downstream side of the dam. Their roots penetrated underneath the dam and may also have contributed to the piping of water.

The entire foundation of the dam was exposed. The part of the dam that had been undercut had to be sealed and underpinned. Both sides of the 1.5 meter wide masonry foundation were concreted shut with 3/4 inch PVC pipes installed for grout injection. A hand grout pump was built locally which could deliver 200kPa of pressure. A grout mix of 1 cement to 3 parts of sand by volume was used with a 5 per cent bentonite to cement ratio. The wall of the dam around the intake canal to the power house had been destroyed, with a large structural crack emanating out from it. This area was rebuilt with concrete. The crack was grouted with a grout mix of 1 cement to 3 parts sand.

Clay was not locally available for use as an impermeable compacted fill. The least expensive alternative was provided by purchasing two tons of bentonite from a mine 550 kilometres away. Mixed at 20 per cent volume with the local soil, this provided an impermeable material. The upstream side of the foundation resting on the permeable base was backfilled with this. A two meter wide, 15 centimetre thick apron of this fill was placed adjacent to the foundation that rested on the weathered limestone.

Analysis of the masonry core of the dam showed only a 5 per cent factor of safety against overturning. Two-thirds of the dam had previously been backfilled on both sides, providing the needed stability. This washed out section was re-backfilled. The solution for the other third of the dam, which rested on limestone, was to construct the new turbine power house there, supporting the dam in buttress fashion.

The reconstruction of the dam was very labour intensive. Ten men were employed for eight months for removing debris, digging, backfilling, hand breaking rock with hammers into gravel, removing trees and roots, and dredging of the downstream channel.

Power generation

Removal and dismounting of the turbine revealed that it had suffered no damage from the explosion. The turbine was a 16 inch diameter, cast iron Francis Turbine, build by Fitz Water Wheel Co., Pa., USA. It was installed in 1952, and had been submerged in water for 44 years. During the nine years of inoperation after the attack, it was frozen up by rust. It required six months to disassemble it using heat, lubricants and sweat. Several minor parts had to be remachined and mainly bushings needed to be replaced. All parts needed extensive cleaning of rust and repainting. The wiring of the old electrical motors, generators and transformers was recycled into wiring for use in the electrical distribution grid.

The previous turbine powered a shaft off of which equipment was mechanically driven through pulleys. The flow control vanes were manually controlled to adjust water volume and power production. The new system produces only electricity at the run-of-the-river flow, therefore the flow is set at a constant volume. To make use of the energy storage capacity of the dam, a mechanical means of regulating the vanes is still being considered.

A 11 kVA induction generator is being used, producing 380 volt, three phase, 50 hz power. In spite of the small energy output, three phase current is being used instead of single phase because of the resulting savings in 1000 meters of transmission wire and to power the existing 3 phase water pump and other existing motors. Governing is provided by an induction generator control (IGC), which keeps the generator output load at a constant so as to control the voltage and frequency. An IGC measures the generator output voltage, which it then regulates by diverting varying amounts of power to ballast loads. The ballast loads are refrigeration and heating units.

Conclusion

The decision to rehabilitate the hydro-electric facility could only be made because of the presence of an engineer to supervise this small but complex project over a year's time. If sufficient water head would have been available without the need for a dam, a cost effective and less complex project could have been built by using a new turbine, generator and control package produced by one manufacturer. The easiest alternative would have been using solar energy. As it was, this labour intensive project provided work for local people instead of spending this same money on imported manufactured equipment. It continues to provide much needed revenue and employment.

Reference

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