International Journal of Advanced Engineering Research and Science (IJAERS)
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-8, Issue-1; Jan, 2021
Journal Home Page Available: https://ijaers.com/
Journal DOI: 10.22161/ijaers
Article DOI: https://dx.doi.org/10.22161/ijaers.81.40

Analysis of Economic Viability of the Repowering of Hydroelectric Plant

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Received: 21 Oct 2020;
Received in revised form:
09 Jan 2021;
Accepted: 19 Jan 2021;
Available online: 31 Jan 2021

***Keywords*— Small Hydroelectric Plants. Economic viability. Repowering.**

Abstract*— *The present study aimed to carry out an economic feasibility study for the repowering of Small Hydroelectric Plants - SHPs. Through the application of economic parameters, it was possible to evaluate the potential gains obtained through repowering. The case study was carried out at Martinuv SHP, located in the city of Vilhena / RO.

I. INTRODUCTION

For Maldonado et al. (2006), with repowering, it is possible to maximize the energy efficiency of the plant without generating major socio-environmental impacts, considering that the impacts have already been consolidated and there is no need for compulsory removal of riverside populations. In addition, when there is no change in the level of the reservoir, any chances of erosion along the river are discarded.

The economic viability of the repowering project will be confirmed when the price of the cost of the energy produced (R$/kWh) reaches values lower than the commercialization, that is, this relationship is considered as a sensitivity index (attractiveness) in the selection of the best projects repowering in which the investment should be made (VEIGA, 2001).

The choice of the best repowering alternative for a given project is made, from an economic point of view, through the joint analysis of specific methods, commonly used for the analysis of investments in projects. The main methods used and which contribute to decision making will be discussed below.

II. METHODOLOGY

The investment analysis methods that will be applied in this study are: NPV, IRR and payback. These methods also take into account the minimum rate of attractiveness - TMA.

2.1 Net Present Value Method - NPV

According to Rebelatto (2004) the NPV consists of bringing the capital inflows and outflows to the zero investment date, discounting the interest rate, it is a method generally used in the evaluation of alternatives and selection of projects. When the NPV is positive (NPV> 0), it means that the project has an income rate higher than the interest rate considered, thus being economically viable. Otherwise (NPV <0), the project must be rejected, as the return would be lower than the interest rate. The NPV can be obtained through equation 1:

$$NPV = \sum_{t=0}^{n} \frac{FC_t}{(1+i)^t} - FC_0 \quad (1)$$

Where,

NPV = Net Present Value;

FC_0 = Cash flow verified at time zero (initial);

FC_t = Cash flow in period t (expected).

i = Interest rate;

n = number of periods considered.

2.2 Internal Rate of Return - IRR

It is defined as the discount rate that equals the net present value (NPV) to zero, making the present value of the inputs equal to the initial investment. In other words, it is the annual rate of return that the company would obtain if it completed the project and received the cash inflows as planned (GITMAN, 2007). From equation 1, the IRR equation is obtained:

$$FC_0 = \sum_{t=0}^{n} \frac{FC_t}{(1+IRR)^t} \quad (2)$$

For evaluation criteria, if the obtained IRR is greater than the cost of capital invested (minimum attractiveness rate) the project is viable and can be accepted, otherwise (IRR <minimum attractiveness rate) it must be rejected.

2.3 Simple Payback

According to Schaicoski (2002), the simple payback can be defined as the period in which the investment values (negative flows) cancel each other out with the cash values (positive flows). In other words, it is the time that a given investment takes to be repaid.

As an analysis criterion, the project must be accepted if it presents a payback below the minimum defined and expected by the company, defined according to its business strategies (MOTA; CALÔBA, 2002). The simple payback can be obtained through Equation 3:

$$PBs = \frac{I}{BA} \quad (3)$$

Where:

PBs - Simple payback;

I - Total investment;

BA - Net annual benefit.

2.4 Discounted Payback

The concept of discounted payback is similar to that of simple payback, but it takes into account the time factor in the value of money, bringing future values of cash flow to present value (ASSAF NETO; LIMA, 2011). That is, this method intends to measure the time necessary for the sum of the discounted installments to be, at least, equal to the initial investment. When considering the value of money over time (discounted cash flow), it is noticed that the period for return on investment increases.

2.5 Benefit / Cost Ratio

It is an indicator used to compare the present value of net benefits with the investment value of the project (OLIVEIRA, 2012). It can be expressed as:

$$R_{B/C} = \frac{BA}{I}$$

For a project to be viable, the $R_{B/C}$ must be greater than 1.

III. RESULTS AND DISCUSSION

The plant selected for the application of the methodological proposal for technical and economic feasibility analysis will be the Martinuv Small Hydroelectric Plant. In the search for repowering alternatives for the plant, all elements of the plant were analyzed, from the dam to the generation itself, in the powerhouse.

Martinuv SHP underwent a repowering process, in the extension modality, in 2017. Until then, the plant had only Generator Unit 1, with a power of 950 kW. The generating units are in excellent generation conditions, with levels of income above average. However, despite the installed capacity being 1.84 MW, the average monthly generation, considering the range from 2017 to 2019, is 1069.52 MW.

Considering that, from the plant's maintenance history, the generating units do not present operational problems, such as, for example, excessive vibration and the occurrence of cavitation, added to the fact that the plant operates with approximately 60% of the total power, the hypotheses were dispensed with extension of the powerhouse. Following with the field analysis, the possibility of obtaining energy gains through works on the CGH adduction channel was verified.

3.1 Investment cost

A survey of the costs involved in covering the plant's adduction channel through High Density Polyethylene - HDPE geomembranes was carried out. In order to determine the best alternative, the main suppliers were consulted and, then, three geomembrane alternatives were compared, as shown in Table 1.

Table 1 - Costs of coating with HDPE geomembrane

ADDITION CHANNEL COATING			
Costs	**ALTERNATIVE I HDPE Geomembrane 0.65 mm (Aquamat)**	**ALTERNATIVE II HDPE Geomembrane 0.8 mm**	**ALTERNATIVE III HDPE geomembrane 1.0 mm**
Geomembrane	R$ 175.770,00	R$ 130.720,15	R$ 153.130,82
Geotextile	R$ 64.000,00	R$ 64.000,00	R$ 64.000,00
HDPE profile	R$ 1.410,00	R$ 1.410,00	R$ 1.410,00
Support	R$ 1.500,00	R$ 1.371,06	R$ 1.371,06
Installation	R$ 37.654,00	R$ 37.654,00	R$ 37.654,00
Civil / Earthworks	R$ 24.000,00	R$ 24.000,00	R$ 24.000,00
Taxes	R$ 26.365,50	R$ 19.608,02	R$ 22.969,62
Freight	R$ 9.700,00	R$ 9.566,00	R$ 10.350,00
Investment cost	R$ 340.399,50	R$ 288.329,23	R$ 314.885,50

Source: The author (2020).

During the period of execution of the work (preparation and installation of the geomembrane), the plant interrupts the electrical generation, therefore this period must be considered in the feasibility study.

The downtime, obtained by applying the PERT/CPM network diagram, is 15 days. As the average monthly generation is 1069.52 MWh, there is a generation of 35.64 MWh / day. Therefore, the cost of unavailability (C_{un}) is given by:

$$C_{un} = Daily\ generation\ x\ TME\ x\ days\ without\ operation \quad (5)$$

$$C_{un} = 35{,}64\ x\ 209{,}8\ x\ 15$$

$$C_{un} = R\$\ 112.192{,}65$$

The total cost (C_{TOTAL}) is given by the sum of investment costs and unavailability, therefore:

$$C_{TOTAL} = C_{INVEST} + C_{un}$$

The total cost associated with each alternative is shown in Table 2.

Table 2 - Total cost

Alternative	Total Cost
I	R$ 452.592,15
II	R$ 400.521,88
III	R$ 427.078,15

Source: The author (2020).

3.2 Economic analysis

The economic return obtained directly through the repowering work under study, with respect to the reduction of head loss and flow gain, can be measured, as shown in Table 3.

Table 3 - Annual gain due to repowering

ANNUAL GAIN DUE TO INCREASED FLOW	
Qi [m³/s]	0,00888
Flow Gain [%]	0,404%
Generation Gain [R$/ano]	R$ 10.867,43
ANNUAL GAIN DUE TO REDUCED FRICTION	
Generation Gain [R$/ano]	R$ 63.435,23

Source: The author (2020).

Therefore, the annual return due to increased flow and reduced friction consists of an amount of R $ 74,302.66, considering the current average tariff. In order to estimate future revenue, the trend of increasing the price of TME from ANEEL's auctions (Figure 35) was used, which in the last 10 years has presented an average annual increase of 6.44%.

The discount rate adopted was 3%, taking into account the current basic interest rate (SELIC), which is 2% (value in effect in August 2020). The economic parameters VP, VPL, TIR, TL and discounted Paypack, for each alternative, are shown below. The economic parameters of Alternative I are shown in Table 4.

Table 4 - Economic analysis - CGH Martinuv (Alternative I)

ECONOMIC ANALYSIS - CGH MARTINUV			
Total Cost	R$ 452.592,15		
Discount rate	3,00%		
Period (Year)	**Cash flow**	**Present value**	**Accumulated PV**
0	-R$ 452.592,15	-R$ 452.592,15	-R$ 452.592,15
1	R$ 74.302,66	R$ 72.138,51	-R$ 380.453,64
2	R$ 79.087,75	R$ 74.547,79	-R$ 305.905,85
3	R$ 84.181,00	R$ 77.037,54	-R$ 228.868,31
4	R$ 89.602,26	R$ 79.610,45	-R$ 149.257,86
5	R$ 95.372,65	R$ 82.269,28	-R$ 66.988,58
6	R$ 101.514,64	R$ 85.016,92	R$ 18.028,34
7	R$ 108.052,19	R$ 87.856,32	R$ 105.884,66
8	R$ 115.010,75	R$ 90.790,55	R$ 196.675,20
Sum PVs (Year 1 to 8)	**R$ 649.267,35**		
Project NPV	**R$ 196.675,20**		
Internal Rate of Return (IRR)	**11,68%**		
Profit Rate (TL)	**1,43**		
Payback Time (Discounted)	**5,79**		

Source: The author (2020).

Figure 1 shows a projection of the project's accumulated present value over the plant's useful life, considering alternative I.

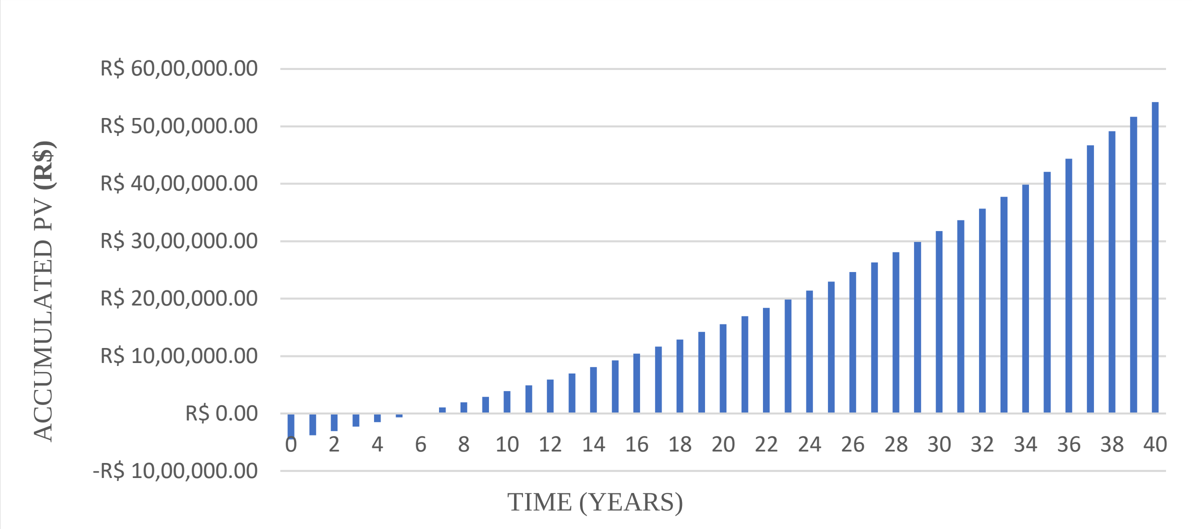

Fig.1: Accumulated Present Value x Lifetime Curve (Alternative I)

Source: The author (2020).

The economic parameters of Alternative II are shown in Table 5.

Table 5 - Economic analysis - CGH Martinuv (Alternative II)

ECONOMIC ANALYSIS - CGH MARTINUV			
Total Cost	R$ 400.521,88		
Discount rate	3,00%		
Period (Year)	**Cash flow**	**Present value**	**Accumulated PV**
0	-R$ 400.521,88	-R$ 400.521,88	-R$ 400.521,88
1	R$ 74.302,66	R$ 72.138,51	-R$ 328.383,37
2	R$ 79.087,75	R$ 74.547,79	-R$ 253.835,58
3	R$ 84.181,00	R$ 77.037,54	-R$ 176.798,04
4	R$ 89.602,26	R$ 79.610,45	-R$ 97.187,59
5	R$ 95.372,65	R$ 82.269,28	-R$ 14.918,31
6	R$ 101.514,64	R$ 85.016,92	R$ 70.098,61
7	R$ 108.052,19	R$ 87.856,32	R$ 157.954,93
8	R$ 115.010,75	R$ 90.790,55	R$ 248.745,47
Sum PVs (Year 1 to 8)	**R$ 649.267,35**		
Project NPV	**R$ 248.745,47**		
Internal Rate of Return (IRR)	**15,00%**		
Profit Rate (TL)	**1,62**		
Payback Time (Discounted)	**5,18**		

Source: The author (2020).

Figure 2 shows a projection of the project's accumulated present value over the plant's useful life, considering alternative II.

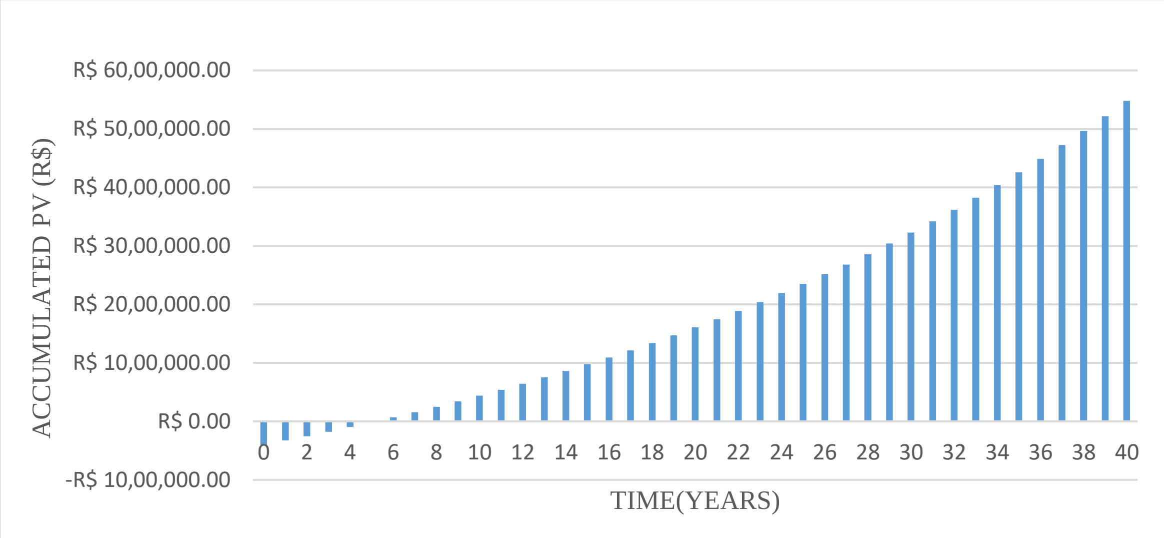

Fig.2: Accumulated Present Value x Lifetime Curve (Alternative II)

Source: The author (2020).

The economic parameters of Alternative III are shown in Table 6.

Table 6 - Economic analysis - CGH Martinuv (Alternative III)

ECONOMIC ANALYSIS - CGH MARTINUV			
Total Cost	R$ 427.078,15		
Discount rate	3,00%		
Period (Year)	**Cash flow**	**Present value**	**Accumulated PV**
0	-R$ 427.078,15	-R$ 427.078,15	-R$ 427.078,15
1	R$ 74.302,66	R$ 72.138,51	-R$ 354.939,64
2	R$ 79.087,75	R$ 74.547,79	-R$ 280.391,85
3	R$ 84.181,00	R$ 77.037,54	-R$ 203.354,31
4	R$ 89.602,26	R$ 79.610,45	-R$ 123.743,86
5	R$ 95.372,65	R$ 82.269,28	-R$ 41.474,58
6	R$ 101.514,64	R$ 85.016,92	R$ 43.542,34
7	R$ 108.052,19	R$ 87.856,32	R$ 131.398,66
8	R$ 115.010,75	R$ 90.790,55	R$ 222.189,20
Sum VPs (Year 1 to 8)	**R$ 649.267,35**		
Project NPV	**R$ 222.189,20**		
Internal Rate of Return (IRR)	**13,23%**		
Profit Rate (TL)	**1,52**		
Payback Time (Discounted)	**5,49**		

Source: The author (2020).

Figure 3 shows a projection of the project's accumulated present value over the plant's useful life, considering alternative III.

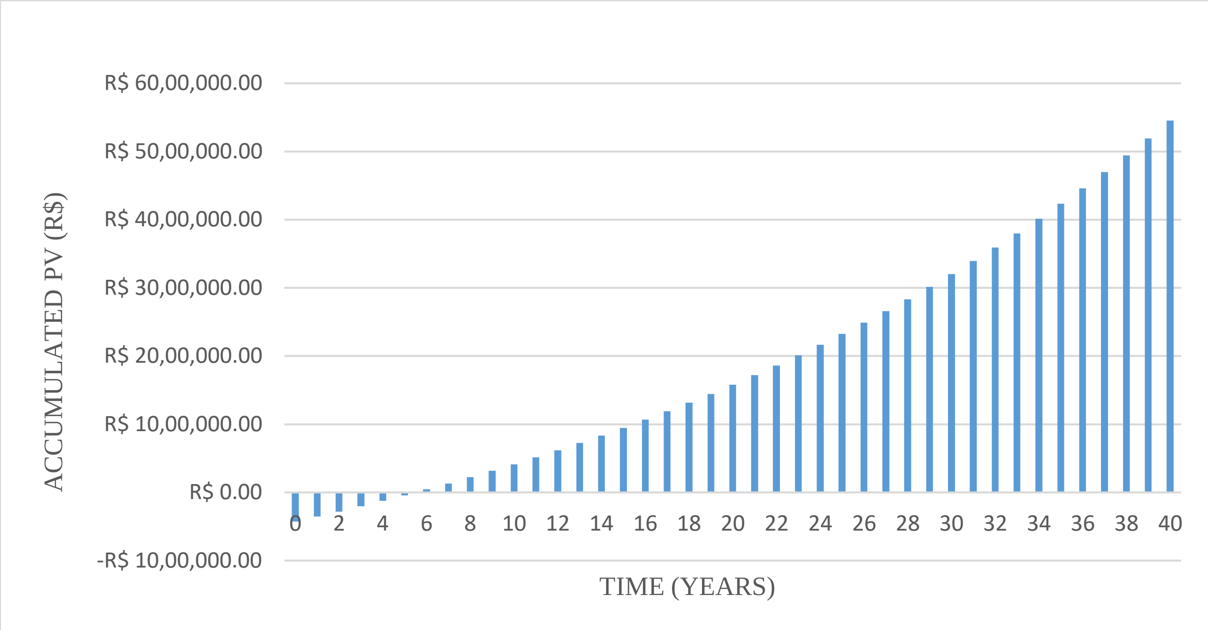

Fig.3: Accumulated Present Value x Lifetime Curve (Alternative III)

Source: The author (2020).

Through the graphical analysis it is verified that throughout the useful life of the enterprise the NPV accumulated for each alternative presented similar results. The NPV over 40 years for alternatives I, II and III is R $ 5,425,512.86, R $ 5,477,583.13 and R $ 5,451,026.86, respectively.

3.3 Summary of economic evaluation

Through the economic viability analysis carried out, the repowering project under study proved to be highly viable for the project. The summary of the economic study is shown in Table 7.

Table 7 - Summary of the economic evaluation

Parameter	Alternative I	Alternative II	Alternative III
Total Cost	R$ 452.592,15	R$ 400.521,88	R$ 427.078,15
Sum PVs (Year 1 to 8)	R$ 649.267,35	R$ 649.267,35	R$ 649.267,35
Project NPV	R$ 196.675,20	R$ 248.745,47	R$ 222.189,20
Internal Rate of Return (IRR)	11,68%	15,00%	13,23%
Profit Rate	1,43	1,62	1,52
Payback Time (Discounted)	5,79	5,18	5,49

Source: The author (2020).

It should be noted that in addition to the revenues used in economic calculations, there is an indirect economic return due to the reduction in the cost of maintaining the adduction channel and the plant's equipment.

IV. CONCLUSION

The repowering process proved to be very advantageous and comprehensive. Martinuv SHP (Vilhena/RO) is a power plant that, after ten years of operation, underwent a repowering process in the expansion modality, in which it doubled its generation capacity (installed power) and even so presents possibilities for increment, as demonstrated in the present study, involving the lining of the adduction canal. The economic evaluation showed that the return on investment is easily achieved, as demonstrated through the discounted payback of 5.79 years.

As for the lining of the adduction channel, the use of the Aquamat Flex HDPE geomembrane proved to be the most technically and economically feasible choice, enabling sustainable energy gains, without causing new environmental impacts.

REFERENCES

[1] ASSAF NETO, Alexandre; LIMA, Fabiano Guasti. **Financial Management Course**. 2. ed. São Paulo: Atlas, 2011.

[2] GITMAN, L. J. **Financial Management Principles**. 10ª edição, São Paulo: Harbra. 2007.

[3] MALDONADO, O. A.; SILVEIRA, J. L.; PANUNZIO, P. A.; GYORI, D. F. S. Technique economical Viability of Repowering of Small Hydroelectric Power Plant considering the Social and Environmental Insert. In: **THE INTERNATIONAL CONFERENCE ON RENEWABLE ENERGIES AND POWER QUALITY**, 4. 2006, Palma de Mallorca, 2006. v.1. p. 50-55. Available in: <http://www.icrepq.com/icrepq06/293-maldonado.pdf>.

[4] MOTTA, Regis da Rocha; CALÔBA, Guilherme Marques. **Investment Analysis: decision making in industrial projects.** São Paulo: Atlas, 2002.

[5] OLIVEIRA, M. A. **Repowering of Small Hydroelectric Plants: technical and economic evaluation.** 195 f. Dissertation (Master in Energy Engineering) - Federal University of Itajubá, Itajubá, 2012.

[6] REBELATTO, D. A. N. **Investment project: with complete case study in the services area**. Barueri: Manole, 2004.

[7] SCHAICOSKI, J. C. **The use of ROI in the analysis of information technology projects.** 2002. Dissertation (Master) - Federal University of Santa Catarina, Florianópolis, 2002.

[8] VEIGA, J. R. C. **Business opportunities with the repowering of plants - technical, economic and environmental aspects.** 108f. Dissertation (Master in the inter-unit graduate program in energy) - Polytechnic School, University of São Paulo, São Paulo, 2001.