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Feasibility analysis of micro hydro plant at nawangan village of pacitan district

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Abstract: Nawangan Village of Pacitan District utilizes Kedung Pasang Micro Hydro Plant (MHP) as a power source, but the existing electricity power unable suffice the demand so it needs revitalization by calculating the new unit price and debit because of the previous reference already invalid. The problem is that the investment required for the construction of the MHP must provide benefits for a certain period. This study analyzed the ratio of power and energy potential of MHP with changes in pipe diameter and speed of existing turbines, and calculated the cost. The available power is currently at 112.5 kW and energy is 82150.66 kWh. The results of the analysis show that the power increase can be done up to 142,95 kW a year or equivalent 218%, the energy can be done up to 139.427 kWh a year, meanwhile the benefit is Rp44.566.169, increase Rp26.604.588,- from existing condition or equivalent 148,1% which is done by changing the diameter of penstock and the turbine. Economic analysis of Kedung Pasang MHP development plan shows NPV of Rp6.717.110,- that is greater than 0, the value of IRR is 11% greater than the interest rate set by Bank Negara Indonesia 46 of 10,25% and BCR value of 1,19 is greater than 1, thus the revitalization of Kedung Pasang MHP feasible to be implemented.

Keyword : Increased electrical power, energy, MHP, Nawangan

1. Preliminary

Provision of power source that adequate, inexpensive, and environmentally friendly is one of the requirements for sustainable socio-economic development. However, the supply of electricity in rural areas is still limited. Micro Hydro Plant (MHP) is a power plant that produces small-scale power (<100 kWh) can be an alternative solution [1]. The benefit of Micro Hydro Plant (MHP) which does not affect much of the environment or reduce water for agricultural purposes does not require local community relocation due to dam construction and does not require fuel so it does not emit greenhouse gas emissions. Nawangan Village of Pacitan District in 1994 has been built and operated Micro Hydro Plant (MHP) Kedung Pasang as an alternative source of electricity that has been utilized by 60 heads of households but the power generated does not meet the needs of the electricity users during the dry season, so it needs analysis of re-planning [2]. This study examines the potential power and suitability of potential available to the possibility of increasing electric power and the calculation of financial feasibility of MHP Kedung Pasang based on the price of the work unit in 2016.

(Regulation of Minister of Public Works and Public Housing Number: 28 / PRT / M / 2016 about Unit Price Analysis Work Field of Public Works).

2. Review of Literature And Basis Theory

2.1. Watershed

Watershed is a land area that is topographically constrained by the ridges of the mountains that hold and store rainwater to then channel it into the sea through the main river [3]. Watershed has specific characteristics and is closely related to the main elements such as soil type, land use, topography, slope, and slope length [4].

2.2. Field Data

The field data were obtained from the survey of existing conditions of Micro Hydro Plant (MHP) Kedung Pasang in the previous research, covering the width of 4 m wide, 3 m high, the average depth of 1.5 m (river sediments reach +1m from the bottom of the river), sediments 13.7 m x 2.8 m x 7.5 m (length x wide x water depth), 25 cm long pipe with 48 m long, turbine house, number of household heads of electric users, and head height available.

2.3. Evapotranspiration

Evapotranspiration is a combination of evaporation and transpiration or in other words, evapotranspiration is the amount of water used to grow crops and evaporate water from the soil as aquaculture [5]. In this study used the Penman-Monteith method (Monteith, 1965) for calculating evapotranspiration as mentioned on SNI 7745; 2012 at Equation 1.

$$ET_0=\frac{0{,}408\Delta(R_n\text{-}G)+\gamma\,\frac{900}{T+273}\,u_2(e_s\text{-}e_a)}{\Delta+\gamma(1+0{,}34u_2)} \tag{1}$$

ET0 : evapotranspiration of reference plants (mm / month), Rn : net sun radiation above plant surface (MJ/ m^2/day), T : average air temperature (° C), U2 : wind speed at a height of 2 m above ground level (m / s), Es : saturated water vapor pressure (kPa), Ea : actual water vapor (kPa), Δ : slope of water vapor pressure curve to temperature (kPa / ° C), Γ : psychometric constants (kPa/°C).

2.4. Analysis of Consistency Rainfall Data

Double mass analysis tested the consistency of measurement results at a station and compared the annual or seasonal rainfall accumulation with the combined mean value of accumulation for a set of adjacent stations [4][6]. The deterministic coefficient shows how far the error in estimating the magnitude of the bound variable y can be reduced using the information of the free variable x. The regression model is said to be perfect when $r^2 \approx 1$ [7] as showed at Equation 2.

$$r^2 = \frac{\Sigma x_i y_i - \frac{\Sigma x_i \Sigma y_i}{n^2}}{\Sigma x_i{}^2 - \frac{(\Sigma x_i)^2}{n} \Sigma y_i{}^2 - \frac{(\Sigma y_i)^2}{n}} \tag{2}$$

i : data number-, n : amount of data.

2.5. Monthly Average Rainfall by Arithmetic Average Method

The arithmetic mean method is performed by measuring all the precipitation at the specified station and summing it up entirely. Then the result of the sum is divided by the number of observation rainfall station it will produce the average rainfall at MHP Kedung Pasang as calculated at Equation 3. The observed rainfall stations are Nawangan rainfall station and Pacitan rainfall station.

$$\text{CHaverage} = (\Sigma \text{Ri}) / n \tag{3}$$

CHaverage : mean rainfall (mm), Ri : magnitude of CH at station i (mm), n : number of rainfall stations.

2.6. Debit Transformation by Global Rainfall Runoff Method

GR2M (Global Rainfall-Runoff Model) is one of the conceptual methods based on the concept of water balance [8]. According to Perrin [9], parameters used for calibration of model GR2M version Mouelhi et al. (2006) [10].

Table 1. GR2M Parameters

Parameter	Average	Interval at the level of trust 90%
X_1 (mm)	380	140 – 640
X_2	0,92	0,21- 1,31

X_1 : soil moisture storage capacity (SMC), X_2 : groundwater absorption coefficient.

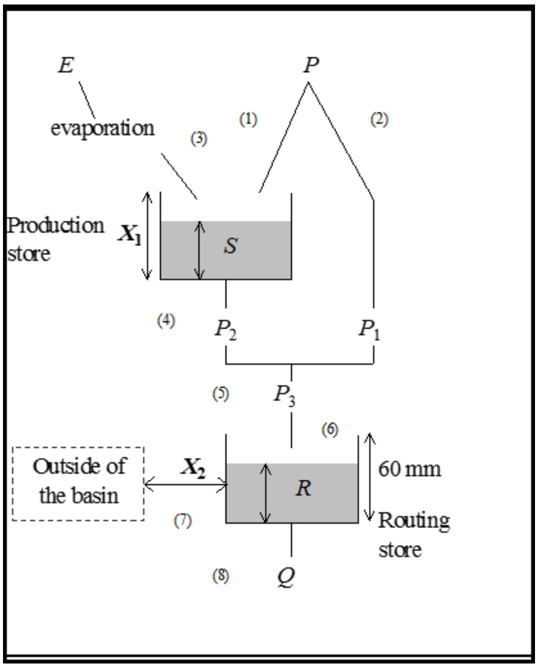

Figure 1. GR2M model

Figure 1. explaines the GR2M model sketch and The equations used in this model (Mouelhi, 2006) are described on the Equation 4 to 12 :

$$S_1 = \frac{S_0 + X_i\,\varphi}{1+\varphi\,\frac{S}{X_1}} \tag{4}$$

$$P_1 = P + S_0 - S_1 \tag{5}$$

$$S_2 = \frac{S_1(1-\psi)}{1+\psi\,(1-\frac{S_1}{X_1})}\ ;\ \psi = \tanh(\frac{E}{X_1}) \tag{6}$$

$$S = \frac{S_2}{1+\frac{S_2}{X_1}^{\frac{1}{3}}} \tag{7}$$

$$P_2 = S_2 - S \tag{8}$$

$$P_3 = P_1 - P_2 \tag{9}$$

$$R_1 = R - P_3 \tag{10}$$

$$R_2 = X_2\ x\ R_1 \tag{11}$$

$$Q = \frac{{R_2}^2}{R_2+60} \tag{12}$$

S_1: soil moisture due to precipitation (mm/month), S_0: initial soil moisture (mm/month). The initial soil moisture value for the first month of maximum calculation is X1, while the initial soil moisture value for another month is S in the previous month (mm/month). P: monthly rainfall (mm / month), P_1: surface flow (mm/month), X_1: maximum soil moisture (mm/month), S_2: soil moisture due to precipitation and evapotranspiration (mm/month), E: evapotranspiration (mm/month), S_3: soil moisture due to infiltration to the soil layer (Mm/month), P_2: rain depth due to S2-S reduction (mm/month), P_3: total rain depth (P_1 + P_2) (mm / month), R: routing value (mm/month), The routing value for the first month of calculation is a maximum of 60 mm / month, while the routing value for the other month is R in the previous month (mm/month), Q: Runoff discharge (mm/month).

2.7. Basic Year of Planning (Basic Year Method)

The mainstream debit analysis of Kedung Pasang MHP is determined based on the basic year of planning (Basic Year) using Equation 13.

$$R_{80} = (n / 5) + 1 \quad (13)$$

R_{80} = mainstay discharge used (m^3/sec), n = number of years

2.8. Micro Hydro Building Planning

This research focus on replacing penstock and turbine, turbine house is excluded.

2.9. Economic Analysis

Economic analysis of Kedung Pasang MHP research bases on the ratio of output and cost to create the principle of cost effectiveness. In this economic analysis using parameters, namely:

2.9.1. Benefit Cost Ratio (BCR)

BCR is the comparison between the equivalent value of the benefit and the equivalent value of the cost at the same time point (Equation 14), for example, present worth, future worth (future) or annual worth.

$$BCR = \frac{\sum_{i=t}^{i=n} \frac{B_t}{(1+i)^t}}{\sum_{i=t}^{i=n} \frac{C_t}{(1+i)^t}} \quad (14)$$

Bt = benefit every year, C_t = cost in each year, 1/(1 + i) t = the formula pv (present value), t = 1,2,3, ..., n = number of years, i = interest rate (%).If BCR $\geq$ 1 then the project is feasible to implement, BCR <1 then the project is not feasible to be implemented.

2.9.2. Net Present Value (NPV)

NPV is the sum of all benefits reduced by the total cost at a point in time using Equation 15.

$$NPV = \sum_{i=t}^{i=n} \frac{(B_t - C_t)}{(1+i)^t} = 0 \quad (15)$$

B_t = benefit every year, C_t = cost in each year, 1 / (1 + i) t = the formula pv (present value) t = 1,2,3, ..., n = number of years, i = interest rate. If NPV positive or $\geq$ 0; then the project is feasible to implement but if NPV is negative or <0; then the project is not feasible to implement.

2.9.3. Internal Rate of Return (IRR)

IRR is very important to know the extent to which the ability of this project can be financed by looking at the value of the applicable loan. The calculation can be seen at Equation 16.

$$IRR = \frac{NPV_1}{r_1 + (NPV_1 - NPV_2)x(r_2 - r_1)} \quad (16)$$

PV_1= benefit year-1, NPV_2 = thenext year benefit, r_1 = lower interest rate, r_2 = higher interest rate. If IRR > defined interest rate, feasible project to be implemented, but if IRR < defined interest rate, the project is not feasible to implement.

3. Research Methods

The method used in this research is quantitative descriptive research by comparing the power, energy, benefits of Kedung Pasang MHP existing and plans then concluded its financial feasibility.

4. Results and Discussion

The variables used in the calculation of financial feasibility of this MHP are monthly evapotranspiration and monthly rainfall area presented in Table 2 and Table 3.

Table 2. Recapitulation of Monthly Evapotranspiration at Grindulu watershed the year 2006-2016

Year/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	4.49	4.57	4.43	4.11	3.67	3.35	3.54	3.72	4.15	4.43	4.65	4.61
2007	4.49	4.59	4.42	4.11	3.72	3.43	3.43	3.74	4.16	4.43	4.57	4.57
2008	4.48	4.58	4.45	4.07	3.61	3.31	3.4	3.77	4.26	4.54	4.57	4.5
2009	4.49	4.5	4.47	4.16	3.71	3.45	3.39	3.78	4.2	4.46	4.56	4.5
2010	4.5	4.53	4.5	4.15	3.73	3.41	3.49	3.86	4.37	4.5	4.58	4.47
2011	4.5	4.5	4.42	4.1	3.66	3.3	3.39	3.65	4.09	4.58	4.6	4.53
2012	4.48	4.56	4.41	4.11	3.67	3.77	3.36	3.72	4.08	4.49	4.63	4.57
2013	4.51	4.57	4.47	4.17	3.74	3.48	3.37	3.71	4.13	4.48	4.54	4.46
2014	4.48	4.53	4.47	4.12	3.73	3.51	3.48	3.77	4.09	4.43	4.69	4.62
2015	4.62	4.66	4.49	4.12	3.64	3.39	3.42	3.77	4.07	4.43	4.72	4.67
2016	4.51	4.56	4.44	4.12	3.69	3.4	3.4	3.72	4.08	4.47	4.63	4.56

Table 3. Monthly Rainfall Recapitulation

Year/Month	Jan	Feb	Mar	Apr	Mei	Jun
2006	282.5	309.5	241.5	306.5	185.5	36
2007	112.5	377.5	279.5	403.5	139.5	65

2008	268.5	398.5	422.5	219.5	56	0
2009	200	442	121.5	131.5	177.5	59
2010	274	258.5	344.5	276	330	167
2011	369.5	397	335	287	182	6
2012	406	377	387.5	157	133.5	10
2013	581.5	224.5	285	273	171.5	453.5
2014	402.5	170.25	138	125.25	30	241
2015	293.25	250.5	404.25	332.5	96.25	1
2016	246.25	335.75	370.5	286.75	264.25	0

Continuance **Table 3.**

Year/Month	Jul	Ags	Sep	Oct	Nov	Dec
2006	4	0	0	0	5.5	270.5
2007	2	0.5	2	90	301	533.5
2008	0	0	0	152.5	332	155
2009	26.5	1.5	8	100.5	228	168.5
2010	74.5	73.5	290	237.5	324.5	374
2011	3	0.5	0	30.5	198	354
2012	4	0	18.5	58.5	287.5	379
2013	102.5	1	1.5	80.25	287.25	512
2014	87	10	0	4.75	280	545.25
2015	0	0	0	0	231.25	225.25
2016	0	0	0	0	0	0

Furthermore, based on Equation 4-12, the simulation calculation of GR2M debit obtained the results presented in Table 4.

Table 4. Recapitulation of GR2M Simulation of Grindulu Watershed Year 2006-2016 (m^3/sec)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	0.264	0.317	0.184	0.295	0.120	0.037	0.018	0.012	0.009	0.007	0.006	0.158
2007	0.060	0.464	0.232	0.454	0.081	0.040	0.020	0.013	0.010	0.031	0.315	0.671
2008	0.214	0.462	0.462	0.157	0.042	0.020	0.012	0.009	0.007	0.039	0.332	0.092
2009	0.144	0.584	0.072	0.075	0.125	0.045	0.024	0.014	0.011	0.025	0.175	0.109
2010	0.249	0.235	0.345	0.236	0.317	0.105	0.045	0.038	0.293	0.183	0.326	0.385
2011	0.372	0.464	0.315	0.253	0.117	0.034	0.017	0.011	0.009	0.007	0.091	0.364
2012	0.436	0.410	0.402	0.096	0.077	0.029	0.016	0.011	0.009	0.011	0.243	0.397

2013	0.748	0.271	0.272	0.270	0.143	0.563	0.109	0.075	0.072	0.073	0.268	0.658
2014	0.478	0.167	0.107	0.102	0.073	0.204	0.091	0.073	0.071	0.067	0.256	0.718
2015	0.302	0.258	0.462	0.370	0.102	0.077	0.068	0.068	0.070	0.066	0.190	0.192
2016	0.220	0.377	0.413	0.297	0.249	0.090	0.070	0.069	0.070	0.067	0.070	0.066

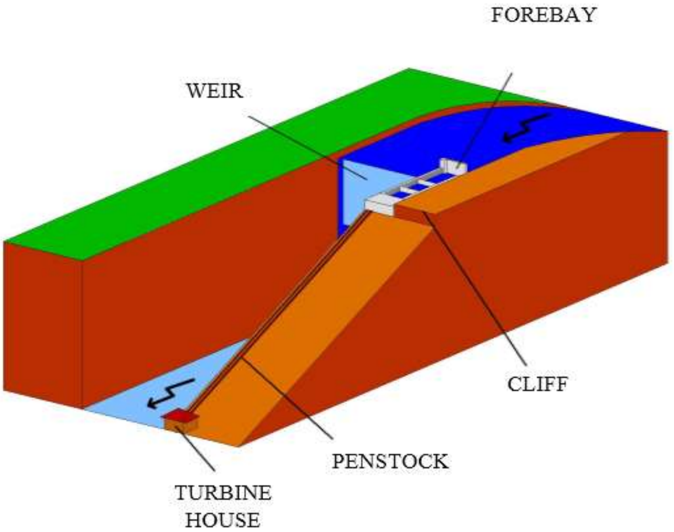

Figure 2. Sketch of Kedung Pasang MHP Planned Condition

Table 5. Comparison of Electric Energy Sales Results Existing and Planned Condition

Month	**Existing**		**Planned**	
	E (kWH)	Benefit (Rp)	E (kWH)	Benefit (Rp)
Jan	4464	2232000	4464	5513633.712
Feb	4176	2088000	4176	5157915.408
Mar	4464	2232000	4464	5513633.712
Apr	4320	2160000	4320	5335774.56
Mei	4464	2232000	4464	5513633.712
Jun	2193.68	1096841.003	2615.78	3230832.66
Jul	1144.42	572209.2365	1359.17	1678758.556
Ags	705.524	352762.1984	1.12614	1390.937886
Sep	518.274	259136.8459	615.467	760184.0896
Oct	689.263	344631.3203	818.538	1011002.909
Nov	4320	2160000	4320	5335774.56
Dec	4464	2232000	4464	5513633.712
Total	**35923.2**	**17961580.6**	**36082.1**	**44566168.53**

From Table 5 it can be seen that the electrical energy and the benefits of Kedung Pasang MHP panned condition have increased and budget draft was obtained amounting

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Rp203.515.363. Furthermore, the calculation continues by calculating the financial feasibility presented in Table 6.

Table 6. Calculations of BCR, NPV, IRR

Year	Outcome	Annual Benefit	Residual value	Net cash flow
0	-Rp203,515,363.32			-Rp203,515,363.32
1	-Rp4,800,000.00	Rp44,566,168.53		Rp39,766,168.53
2	-Rp4,800,000.00	Rp44,566,168.53		Rp39,766,168.53
3	-Rp4,800,000.00	Rp44,566,168.53		Rp39,766,168.53
4	-Rp4,800,000.00	Rp44,566,168.53		Rp39,766,168.53
5	-Rp4,800,000.00	Rp44,566,168.53	Rp114,613,984.91	Rp39,766,168.53
6	-Rp4,800,000.00	Rp44,566,168.53		Rp39,766,168.53
7	-Rp4,800,000.00	Rp44,566,168.53		Rp39,766,168.53
8	-Rp4,800,000.00	Rp44,566,168.53		Rp39,766,168.53
		RESULT		
NPV	Rp6,717,110.24		**FEASIBLE**	
IRR	11%		**FEASIBLE**	
PW	Rp241,915,363.32	Rp235,608,714.48	52505987.07	
B/C		1.19		**FEASIBLE**

5. Conclusion

1) The existing electricity production potential generates the electrical energy of 35923,2 kWh per year and sales proceeds of Rp 17,961,580.6 per year. While the condition of the planned production potential of electricity produces electricity of 36082,1 kWh per year and sales proceeds of Rp 44,566,168,53- per year. This shows that there is a significant increase after the PLTMH is re-planned.
2) Financial feasibility requirements are met so that revitalization of MHP Kedung Pasang is feasible.

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