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The optimal order configuration of turbines in a small hydropower plant: A case study of the Lepenci River in Kosovo

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ABSTRACT

Decentralized electricity production from small hydropower plants used for domestic and ancillary services has been established among the most reliable renewable energy sources for isolated locations. However, many factors impact the energy efficiency and the production capacity of such hydropower plants, one of these factors being the order configuration of the connected turbines. Hence, this research presents a performance evaluation of a small hydropower plant consisting of three francis turbines, and it elicits the optimal order configuration of the connected operating turbines, that yields the highest power output under varying conditions. Three scenarios with different order configurations of turbines are presented and compared in a "run-of-the-river" setting, installed in the Lepenci River, in south-eastern Kosovo. Numerical analyses are used to evaluate the performance of each scenario. The results show that the order configuration of the operating turbines based on their connection order has a significant impact on the electricity production.

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1. INTRODUCTION

The electrification issue of off-grid locations has been an ongoing quest considering that electricity is a basic necessity in general, and in domestic and ancillary services specifically. Small hydropower plants are among the most cost-efficient, reliable, and clean renewable energy sources (RES) that are suitable for remote locations, as long as hydro energy is available and the terrain is suitable to foster the installation of such systems [1]. On the other hand, the use of hydropower plants enables to reach the objective targets on the utilization of RES in Kosovo, where according to the National Renewable Energy Action Plan (2011-2020) [2], by 2020 the achieved rate of RES is 25% mandatory and 29.47% voluntary.

Therefore, the implementation of small hydropower plants has gained momentum in recent years due to the affordable costs of installation, sustainable operation, increasing awareness on the energy consumption mitigation and utilization of available energy, electricity grid independence, and incentives to promote the use of RES [3]. Some of the reported installations and performance evaluations of operating small-scale hydropower plants in Kosovo are presented in [4]-[7]. Other installed hydropower plants were listed in research [8], where the overall potential of renewable energies in Kosovo was discussed.

The electrification of off-grid remote locations presents a challenging task where various solutions have been proposed based on the available energy in the specific location and different hybrid configurations [9], [10]. For example, in research [11] a hybrid power system using photovoltaic solar panels in combination with either diesel or liquified petroleum gas (LPG) generators was proposed. Their analysis was to identify the optimal configuration of a decentralized hybrid power system that showed that the photovoltaic (PV) and LPG generator presents the best solution given the work conditions. Other combinations were also explored for decentralized power systems, such as in [12], where they combined wind, PV, and hybrid energy storage systems, or wind, solar and hydro [13], or only solar energy as in [14]. The most frequent optimization techniques applied in research to optimize the hybrid decentralized energy generation systems are artificial intelligence-based approaches that were discussed in [15]. Whereas a comprehensive review including, cost, reliability, and optimal configuration size of remote hybrid systems were presented in [16]. The same approach was utilized in decentralized hydropower plants specifically, such as in [17] where the optimal location of pumps as turbines was analyzed by optimizing the cost function of the used energy. The yielded results showed that the optimal placement of pumps as turbines in the streamline of water has a significant impact on mitigating the internal energy consumption of water-energy systems up to 30%. However, this study only focused on the position of the turbines in the streamline and not in regard to their orderly position with one another. A similar study was conducted in [18] as well, resulting in the same conclusion but the power generation constraints were also considered. Additionally, the hybrid configuration of turbines as generating units was explored in [19] where two turbines, namely one helical savonius and a delta bladed darrieus turbine, were analyzed depending on the attachment angle. Furthermore, in research [20] a techno-economic analysis was performed on the micro hydropower plant, where the impact of the array formation of the turbines on the total net present cost, cost of energy, and electricity production was discussed. The results showed that the triangular formation of the turbines decreased the total net present cost by 4.83%, the cost of energy by 9.12%, and increased the electricity production by 4.99% compared to the staggered formation. Despite outer configuration analyses, many research studies were focused on the challenges of implementation [21] and internal analysis of the turbines by identifying the optimal parameters inside the turbine [22]-[24]. For instance, in research [25] the impact of pressure fluctuation inside a francis turbine was pointed out, stating that unstable pressure has to be considered when designing a runner designated for variable-speed configurations. Additionally, the impact of variable operating conditions in the francis turbine has been elaborated in research [24], [26] as well.

With all this said, the importance of optimal configuration whether in the turbine or the external setting of the turbines (e.g., position or order), is proven to be of high importance. On the other hand, the configuration of the generating units in hydropower plants has a significant impact on electricity production especially in settings such as in the Lepenci River where the flow rate of water fluctuates during the year [4]. Hence, this research presents a performance analysis to show the impact of the order configuration of three horizontal axis francis water turbines, with different flow rates, in a run-of-the-river setting, on the electricity production potential of the small hydropower plant. This hydropower plant is implemented in the Lepenci River, which is located in south-eastern Kosovo and has an installed capacity of 10 MW. By comparing three scenarios depending on the orderly positions of the connected turbines, the change in the performance of the hydropower plant production will be elicited. This research study is important, as it presents a manner of increasing electricity production by adjusting the orderly position of the turbines in a run-off-the-river setting, to increase the efficient use of limited and fluctuating water flow rates. Further details on the initial phases of design, selection, and implementation of this hydropower plant can be found in research [4], where the optimal flow rate and capacity for each of the three turbines were evaluated, depending on the work conditions on-site.

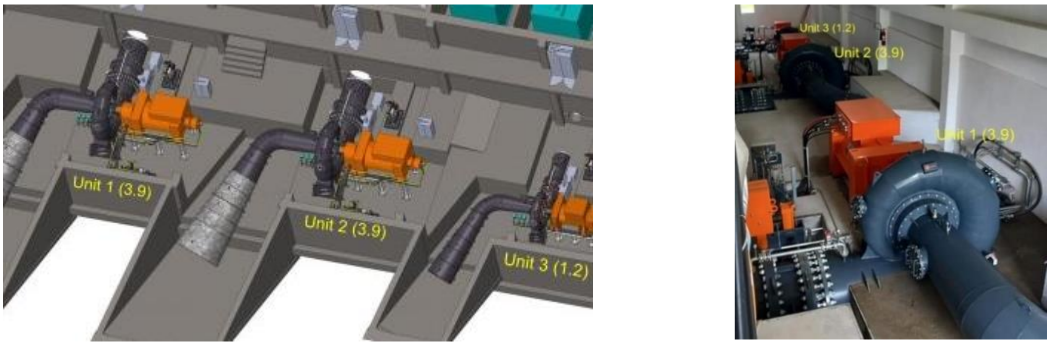
2. METHOD

The hydropower plant is implemented in a run-of-the-river setting, due to the high fluctuation of water flow rates, which makes rivers in Kosovo not suitable for other means of hydropower plants installments [4], [8], [27]. Three scenarios were compared where each of the scenarios represents a different order of the operating turbines based on their design flow rate. The installed configuration scheme is presented in Figure 1(a) and the on-site photograph is shown in Figure 1(b) [4]. The proposed scenarios by switching the positions of the generating units are scenario 1 (S-1) which uses three horizontal axis turbines in this order 1.2/3.9/3.9. These numbers present the design flow rate of the turbine e.g., 1.2 stands for the turbine with a flow rate of 1.2 m^3/s. scenario 2 (S-2) with the turbine order 3.9/1.2/3.9, and scenario 3 (S-3) with the order 3.9/3.9/1.2 [also depicted for illustration in Figures 1(a) and 1(b)]. The characteristics of each turbine are presented in Table 1 according to [4].

This research is based on numerical performance analyses. The data needed to perform the numerical evaluations are retrieved from the Meteorological Institute of Kosovo and the Kosovo Environmental Protection Agency [28]. The technical criterion is that only 66% of the natural flow of the river is to be used for electricity generation or 0.70 m^3/s, whereas the rest of the flow remains intact to avoid negative environmental impact on the biodiversity, according to [30] that addresses hydropower plants in Kosovo.

Table 1. Characteristics of the turbines of the small hydropower plant Lepenci

Characteristics	
Number of units or turbines	2+1
Water discharge per turbine	2 x 3.9 m^3/s + 1 x 1.2 m^3/s
Total water discharge	9 m^3/s
Gross head and net head	138.6 m, 127.1 m
Power per each turbine	2 x 4.36 MW + 1 x 1.3 MW
Total installed capacity	10 MW



(a) (b)

Figure 1. The installation layout of the turbines in the Lepenci River (a), turbine order configuration according to S-3(3.9/3.9/1.2) [29] and (b) on-site photograph of the installation

The amount of water used per each turbine Q (m^3/s), was calculated using the data presented in Table 2, that were measured on-site [29]. The amount of water utilized was the fraction left after the environmental regulations were considered to mitigate the impact on biodiversity.

$$Q = Q_m \cdot n \tag{1}$$

Where Q_m-is the average measured water flow for one month and $n = 0.66$ is the reduction percentage of the water flow from the river due to biodiversity preservation [4], [30].

Table 2. The measured water flow in the river $Q_m, m^3/s$

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Average	10.8	11.4	12.9	14.7	17.8	13.3	8.30	5.30	6.00	7.10	9.70	11.0
Min	1.10	1.00	2.60	1.30	4.80	1.50	1.10	0.70	0.80	1.10	0.90	0.80
Max	34.4	24.8	28.0	31.4	34.3	27.0	23.90	20.2	21.0	28.0	39.6	41.4

After applying the reduction coefficient for all average values from Table 2, and considering that each of the turbines only operates between 30% and 100% of their design flow [4], it was assumed that if $Q < 0.7\ m^3/s$ after the reduction, then the turbines will stop their operation. After these calculations, the monthly $Q_{month}(m^3/s/month)$ and yearly amount of water $Q_y(m^3/s/year)$ was computed by summation. Where d is the number of days within a month. Additionally, the specific annual flow rate ΔQ_y, $(m^3/s/year)$ is calculated using (4), where h is the number of hours:

$$Q_{month} = \sum_{i=1}^{d} Q \tag{2}$$

$$Q_y = \sum_{i=1}^{12} Q_{month} \tag{3}$$

$$\Delta Q_y = Q_y/h \tag{4}$$

The generated power output P_{out} $(MW/year)$ is calculated using:

$$P_{out} = \rho \cdot g \cdot H_n \cdot Q \cdot \eta_t \cdot \eta_g \tag{5}$$

where the water density is estimated $\rho = 1000\ kg/m^3$, the gravitational force $g = 9.81\ m/s^2$, the turbine efficiency $\eta_t = 0.93$ and the generator efficiency $\eta_g = 0.97$. The other needed values were calculated and measured on-site such as the net head $H_n = 118.6\ m$, the water flow $Q = 9\ m^3/s$ [4].

The working hours of the turbines (W_{ty}) were calculated with the assumption that the turbines operate all day, except when there is a lack of water flow. Hence, the yearly working hours are calculated using expression (6) whereas the relative working time using (7):

$$W_{ty} = \sum_{i=1}^{12} W_{month} \quad (6)$$

$$\Delta W_{ty} = W_{ty}\ /h \quad (7)$$

Lastly, the total power output in $(GWh\ /\ year)$ for one scenario is computed using the generated power output P_{out} and the annual working hours of the turbines W_{ty} of the same scenario, respectively:

$$E_{out} = P_{out} \times W_{ty} \quad (8)$$

3. RESULTS AND DISCUSSION

The following section presents the results on how the order position of the connected turbines affects the work profile for each turbine, the water usage, the working hours, and the power output.

3.1. Monthly work profile of the operating turbines

Each of the three francis turbines only operate when their flow rate reaches between 30% and 100% of their design flow [4], in this study the assumption was adopted that the turbines will work only for $Q > 0.7\ m^3/s$. Hence, when the overall water flow rate is lower during particular months of the year, some of the turbines halt their operation. In the following figures, the change in turbine activity through the year is shown in three base scenarios, when the turbine positions are switched among one another.

Figure 2 presents the work profile of the turbines when they are positioned as in scenario S-1 (1.2/3.9/3.9). For instance, the graph named Scenario 1/1=1.2, shows the work profile and water flow of the $1.2\ m^3/s$ turbine. The figure shows that the turbine works steadily during all months, thus, enabling coverage for the whole year. On the other hand, the line for *Scenario 1/1=3.9*, shows the work profile of the 3.9 m^3/s turbine in the S-1 configuration, where it is seen that during the months from July to November this turbine is out of operation due to the lack of sufficient water in the river. Lastly, the third turbine with water flow of 3.9m^3/s according to configuration S-1, presented in the figure as Scenario 1/1=3.9, shows that in these conditions the turbine only works in April and May.

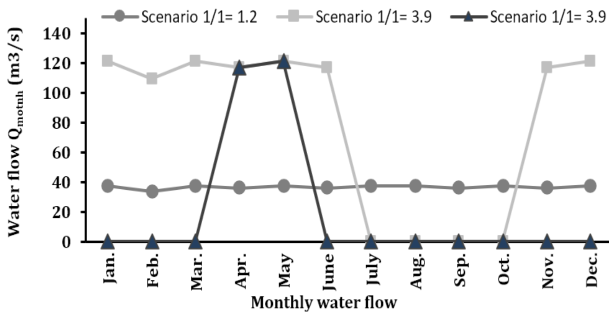


Figure 2. The operational profile of each turbine and the monthly water flow in scenario S-1

Figure 3 shows the work profile of the turbines positioned according to configuration S-2 (3.9/1.2/3.9) and their respective water flow rates per month. It is seen that in August and September there is a lack of water flow for the first turbine of 3.9 m^3/s. Whereas the second turbine of 1.2 m^3/s (Scenario 1/2=1.2), is out of operation from July to November. The third turbine, the same as in S-1, only works in April and May.

Figure 4 shows the work profile and monthly water flows of the turbines in scenario S-3 where the turbines are in this order (3.9/3.9/1.2). It is seen that the first turbine 3.9 m^3/s stops operation in August and

September, due to lack of water flow. The second turbine in this configuration S-3 works only from March to June. Lastly, the third turbine 1.3 m^3/s only operates in April and May. The results show that the combination of the order configuration of the turbine and the available water flow rate highly impacts the work profile of the turbines in each scenario, where only in S-1 there has more coverage all year long.

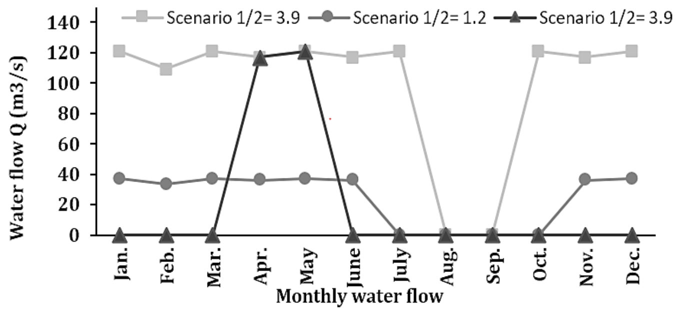


Figure 3. The operational profile of each turbine and the monthly water flow in scenario S-2.

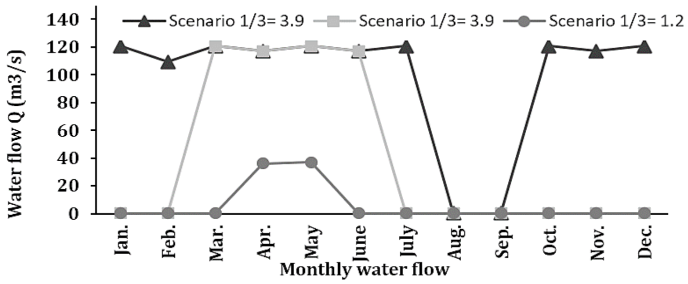
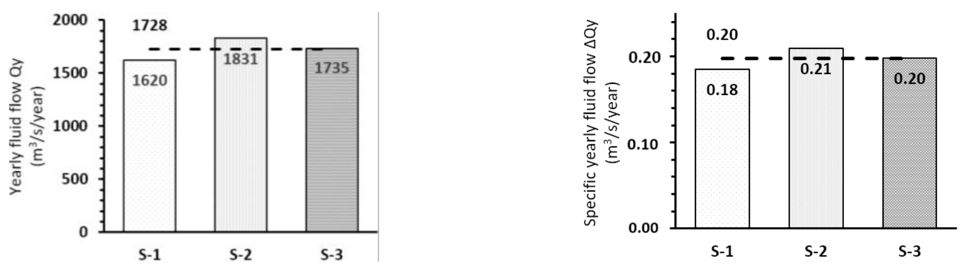


Figure 4. The operational profile of each turbine and the monthly water flow in scenario S-3

3.2. Yearly water flow and specific water flow rates

When considered from a yearly point of view, the overall water flow (Q_y) through the turbines in the three scenarios reached different values as depicted in Figure 5(a) and Figure 5(b) where the specific water flow (ΔQ_y) was presented where Q_y was divided by 8760 hrs to find the specific water flow per hour. The average value of each scenario is presented above the dashed line on the graphs.



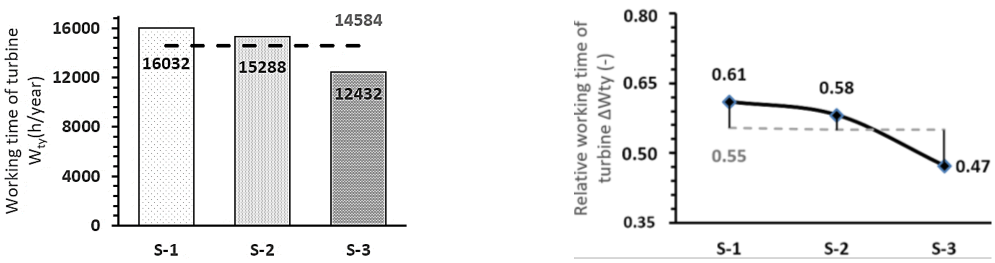
(a) (b)

Figure 5. The water flow through the turbines for each scenario (a) yearly water flow and (b) specific yearly water flow per hour

The results in Figure 5(a) show that scenario S-2 (1831 $m^3/s/year$) has a higher yearly water usage by 6% compared to the average (1728 $m^3/s/year$) and 13% higher than scenario S-1 (1620 $m^3/s/year$). The same applies to the specific yearly water flow shown in Figure 5(b), where the average value is (0.20 $m^3/s/year$) whereas the highest specific yearly fluid flow is shown in S-2 (0.21 $m^3/s/year$). This implies that the order of operational turbines with different capacities has a significant impact on the yearly water flow usage of the turbines, and in this case, when the turbine with lower capacity is positioned between two higher capacity turbines in the same setting, higher yearly water flow usage is reached.

3.3. Working time of the turbines

Depending on the months during the year, the working time of each of the turbines varies significantly due to the fluctuation of water flow, as shown in Table 1. The yearly working time of the turbines in different configurations in the hydropower plants was depicted in Figure 6(a), whereas the relative working time on an hourly basis was shown in Figure 6 (b). The working hours were computed assuming that the turbines work 24 hours in the operational months, and the sum of working hours for each of the turbines in each scenario was presented. It is seen that scenario S-1($16032\ h/year$) has the highest number of working hours per year followed by scenario S-2($15288\ h/year$). The high difference with S-3 ($12432\ h/year$) is attributed to the fact that two higher demanding turbines, namely 3.9 and 3.9 were positioned in a way where the requested flow rate was not reached most of the year for them to operate properly. The differences show that S-1 and S-2 have around 10% and 5% more working hours than the average ($14584\ h/year$), respectively, whereas S-3 has 15% fewer working hours than the average. The relative working hours present the hourly value per year of the working time of the turbines, and Figure 5(b), asserts that their values align, where scenario S-1 has the highest relative working time of the turbines compared to the average (0.55).



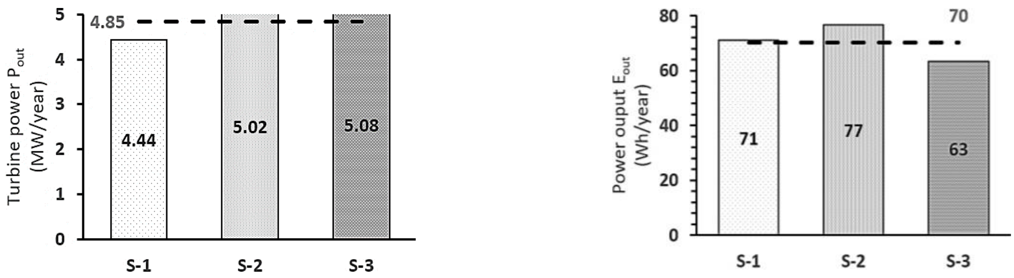
(a) (b)

Figure 6. The working time of the turbines (a) per year and (b) The relative working time per hour.

3.4. Power output of the hydropower plant

On the other hand, and most importantly, the impact of the order configuration of the operating turbines also affects the power output of the small hydropower plant, as shown in Figures 7(a) and 7(b). The obtained results in Figure 7(a) show that the configuration of scenario S-3 has the highest turbine power per year with $5.08 MW/year$, followed closely by the second configuration with the turbine power of $5.02\ MW/year$, the average value is ($4.85\ MW/year$). On the other side, Figure 7(b) shows that the highest power generation of the hydropower plant or the highest power output in GWh/year was reached with the order configuration of the operating turbines as in scenario S-2(3.9/1.2/3.9), where 77 $GWh/year$ were yielded as opposed to S-2 (71 $GWh/year$) and S-3 (63 $GWh/year$), respectively. Meaning that S-2 generates 9% more electricity than the total average (70 $GWh/year$), 8% more than S-1, and 21% more power output than scenario S-3. Concluding that there is a significant change in the power output depending on the order configuration of the operating turbines in a run-of-the-river setting, considering that the turbines operate only when their design flow rate potential is reached.

Lastly, the summary of the change of relative yearly working hours, turbine power in MW, and total power in GWh are presented in Figure 8. Scenario S-1 resulted in higher yearly relative working hours ($0.61\ h/year$), lower turbine power, and moderate power output ($0.47\ MW/year$ and $0.29\ GWh/year$, respectively). Whereas scenario S-2 reached moderate yearly relative working hours ($0.58\ h/year$), moderate turbine power, and higher power output ($0.53\ MW/year$ and $0.31\ GWh/year$, respectively). The outputs from scenario S-3 were lower in terms of yearly relative working hours ($0.47\ h/year$), the turbine power was similar to S-2 ($0.54\ MW/year$), and lower power output ($0.25\ GWh/year$). In other words, Figure 8 shows that the performance of the hydro powerplant consisting of three francis turbines with different flow rate capacities varies depending on the arranged connection of the operating turbines. The results show that the best performing configuration in terms of power output in GWh/year is Scenario S-2 with the turbine order 3.9/1.2/3.9. This outcome shows that the proposed connection manner of the turbines in research [4], can be improved through the configuration of the generating units in the small hydro power plant in the Lepenci River.



(a) (b)

Figure 7. The power output for the (a) turbine per year MW/year and (b) hydro powerplant in GWh/year

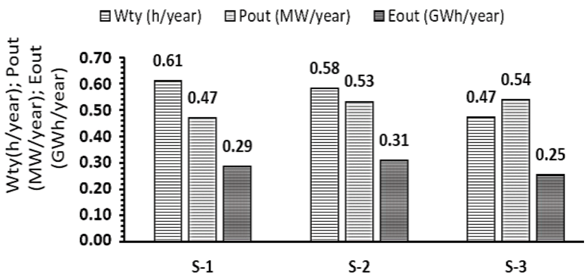


Figure 8. The comparison between the performance of three scenarios in terms of yearly relative working hours in h/year, power output in MW/year and GWh/year

4. CONCLUSION

This research presents the impact of the order configuration of turbines in a small-hydro powerplant with three operating horizontal axis francis turbines as generating units. The small-hydro power plant has an installed capacity of 10 MW and is located along the Lepenci River in Kosovo. The francis turbines have different capacities and flow rates, where one turbine has a power capacity of $1.34MW$, the flow rate is $1.2m^3/s$, whereas for the other two with a capacity of $4.36MW$ and flow rate of $3.9\ m^3/s$, respectively. These three turbines were analyzed for different order combinations of the connected turbines in a “run-of-the-river” setting, enabling three different scenarios that were evaluated and compared to see the impact of the order on the overall performance of the hydro powerplant. The numerical results showed that the order of the turbines, i.e., which turbine is first, second and third, has a significant impact on the performance of the small hydro powerplant. Scenario S-2(3.9/1.2/3.9) outperformed the other two in terms of power output where the order position of the turbines 3.9/1.2/3.9 yielded 7% higher power output than the average, 8% more than scenario S-1(1.2/3.9/3.9), and 21% more power output than scenario S-3(3.9/3.9/1.2). This shows that during the installment of hydro powerplants consisting of more than one turbine, it is important to consider the order position of the connected operating turbines.

REFERENCES

[1] A. K. Akella, M. P. Sharma, and R. P. Saini, “Optimum utilization of renewable energy sources in a remote area,” *Renewable and Sustainable Energy Reviews*, vol. 11, no. 5, pp. 894–908, Jun. 2007, doi: 10.1016/j.rser.2005.06.006.

[2] A. B. Kanase-Patil, R. P. Saini, and M. P. Sharma, "Optimum utilization of renewable energy sources in a remote area,” in \ *Proc. of the International Conference on ‘Advances in Mechanical Engineering*, Des. 2018, pp. 229-234.

[3] V. J. A. Guzmán, J. A. Glasscock, and F. Whitehouse, “Design and construction of an off-grid gravitational vortex hydropower plant: A case study in rural Peru,” *Sustainable Energy Technologies and Assessments*, vol. 35, pp. 131–138, Oct. 2019, doi: 10.1016/j.seta.2019.06.004.

[4] X. Berisha, B. Hoxha, and D. Meha, “Efficiency analyses for small hydro power plant with francis turbine,” *Internation Journal of Modern Trends in Engineering and Research (IJMTER),* vol. 4, no. 10, pp. 155–164, Oct. 2017, doi: 10.21884/IJMTER.2017.4322.ARBMD.

[5] L. Shpetim, N. Lajqi, and B. Hamidi, “Design and construction of mini hydropower plant with propeller turbine,” *International Journal of Contemporary ENERGY*, vol. 2. no.1, pp. 1–13, Feb. 2016, doi: 10.14621/ce.20160101.

[6] S. Lajqi, X. Fejzullahu, N. Lajqi, and H. Hajdini, “Analysis of the mini turgo hydro turbine performance for different working regimes,” 2017. [Online] https://www.semanticscholar.org/paper/Analysis-of-the-Mini-Turgo-Hydro-Turbine-for-Lajqi-Fejzullahu/a3b1e2675bb41fd046e13ecc5690b8b2774ab104.

[7] S. Lajqi, B. Qendresa, B. Arlinda, I. Doçi, and B. Đurin, “Design, implementation and analysis of the overall performance of a micro hydro turgo turbine,” *Journal of Thermal Engineering*, vol. 7, no. 4, no. 4, May 2021, doi: 10.18186/thermal.929958.

[8] S. Lajqi, B. Đurin, X. Berisha, and L. Plantak, "Analysis of the potential for renewable utilization in kosovo power sector," *Environments*, vol. 7, no. 6, Jun. 2020, doi: 10.3390/environments7060049.
[9] B. E. K. Nsafon, H. M. Butu, A. B. Owolabi, J. W. Roh, D. Suh, and J.-S. Huh, "Integrating multi-criteria analysis with PDCA cycle for sustainable energy planning in Africa: Application to hybrid mini-grid system in Cameroon," *Sustainable Energy Technologies and Assessments*, vol. 37, p. 100628, Feb. 2020, doi: 10.1016/j.seta.2020.100628.
[10] A. Micangeli *et al.*, "Energy Production Analysis and Optimization of Mini-Grid in Remote Areas: The Case Study of Habaswein, Kenya," *Energies*, vol. 10, no. 12, no. 12, Dec. 2017, doi: 10.3390/en10122041.
[11] A. Mohamed, Z. Abdelkader, and B. Abdelkrim, "Optimal configuration of hybrid PV-generator (diesel/GPL) for a decentralized production of electricity in Algeria," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11, no. 4, Dec. 2020, doi: 10.11591/ijpeds.v11.i4.pp2038-2045.
[12] H. Oussama, A. Othmane, H. M. Amine, C. Abdesselam, and S. M. Amine, "Proposed energy management for a decentralized DC-microgrid based PV-WT-HESS for an isolated community," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11, no. 4, Dec. 2020, doi: 10.11591/ijpeds.v11.i4.pp2073-2082.
[13] A. H. Nebey, "Design of optimal hybrid power system to provide reliable supply to rural areas of Ethiopia using MATLAB and Homer," *Renewables*, vol. 8, no. 4, Feb. 2021, doi: 10.1186/s40807-021-00067-w.
[14] N. Sharmila, K. R. Nataraj, and K. R. Rekha, "An efficient dynamic power management model for a stand-alone DC Microgrid using CPIHC technique," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 12, pp. 1439-1449, no. 3, Sep. 2021, doi: 10.11591/ijpeds.v12.i3.pp1439-1449.
[15] S. Twaha and M. A. M. Ramli, "A review of optimization approaches for hybrid distributed energy generation systems: Off-grid and grid-connected systems," *Sustainable Cities and Society*, vol. 41, pp. 320–331, Aug. 2018, doi: 10.1016/j.scs.2018.05.027.
[16] S. O. Frimpong, R. C. Millham, and I. E. Agbehadji, "A comprehensive review of nature-inspired search techniques used in estimating optimal configuration size, cost, and reliability of a mini-grid HRES: A systemic review," in *Computational Science and Its Applications – ICCSA 2021*, vol. 12957, pp. 492–507. doi: 10.1007/978-3-030-87013-3_37.
[17] F. Moazeni and J. Khazaei, "Optimal energy management of water-energy networks via optimal placement of pumps-as-turbines and demand response through water storage tanks," *Applied Energy*, vol. 283, p. 116335, Feb. 2021, doi: 10.1016/j.apenergy.2020.116335.
[18] K. D. Nguyen, P. Duc Dai, D. Quoc Vu, B. M. Cuong, V. P. Tuyen, and P. Li, "A MINLP model for optimal localization of pumps as turbines in water distribution systems considering power generation constraints," *Water*, vol. 12, no. 7, Jul. 2020, doi: 10.3390/w12071979.
[19] M. Mosbahi, A. Ayadi, Y. Chouaibi, Z. Driss, and T. Tucciarelli, "Performance improvement of a novel combined water turbine," *Energy Conversion and Management*, vol. 205, p. 112473, Feb. 2020, doi: 10.1016/j.enconman.2020.112473.
[20] A. K. Nag and S. Sarkar, "Techno-economic analysis of a micro-hydropower plant consists of hydrokinetic turbines arranged in different array formations for rural power supply," *Renewable Energy*, vol. 179, pp. 475–487, Dec. 2021, doi: 10.1016/j.renene.2021.07.067.
[21] C. S. Kaunda, C. Z. Kimambo, and T. K. Nielsen, "A technical discussion on microhydropower technology and its turbines," *Renewable and Sustainable Energy Reviews*, vol. 35, pp. 445–459, Jul. 2014, doi: 10.1016/j.rser.2014.04.035.
[22] C. P. Jawahar and P. A. Michael, "A review on turbines for micro hydro power plant," *Renewable and Sustainable Energy Reviews*, vol. 72, pp. 882–887, May 2017, doi: 10.1016/j.rser.2017.01.133.
[23] D. R. Dahal, S. Chitrakar, A. Kapali, B. S. Thapa, and H. P. Neopane, "Design of Spiral Casing of Francis Turbine for Micro Hydro Applications," *Journal of Physics: Conference Series*, vol. 1266, no. 1, p. 012013, Jun. 2019, doi: 10.1088/1742-6596/1266/1/012013.
[24] I. Iliev, E. O. Tengs, C. Trivedi, and O. G. Dahlhaug, "Optimization of Francis Turbines for Variable Speed Operation Using Surrogate Modeling Approach," *Journal of Fluids Engineering*, vol. 142, no. 10, Aug. 2020, doi: 10.1115/1.4047675.
[25] C. Trivedi, E. Agnalt, and O. G. Dahlhaug, "Investigations of unsteady pressure loading in a Francis turbine during variable-speed operation," *Renewable Energy*, vol. 113, pp. 397–410, Dec. 2017, doi: 10.1016/j.renene.2017.06.005.
[26] J. Gomes Pereira, L. Andolfatto, and F. Avellan, "Monitoring a Francis turbine operating conditions," *Flow Measurement and Instrumentation*, vol. 63, pp. 37–46, Oct. 2018, doi: 10.1016/j.flowmeasinst.2018.07.007.
[27] F. Gashi, S. Frančišković-Bilinski, H. Bilinski, N. Troni, M. Bacaj, and F. Jusufi, "Establishing of monitoring network on Kosovo Rivers: preliminary measurements on the four main rivers (Drini i Bardhë, Morava e Binqës, Lepenc and Sitnica)," *Environ Monit Assess*, vol. 175, no. 1, pp. 279–289, Apr. 2011, doi: 10.1007/s10661-010-1511-7.
[28] "BALLINA Agjensioni për Mbrojtjen e Mjedisit të Kosovës -." [Online] http://www.ammk-rks.net/.
[29] Wasserkraft, "Francis turbine." Accessed: Feb. 17, 2022. [online]. Available: https://www.wws-wasserkraft.at/en/products/francis-turbine
[30] INDEP and Balkan Green Foundation, "Hidrocentralet në kosovë -problemet dhe potenciali i tyre real," Mar. 2019. [Online]. Available: ttps://indep.info/wpcontent/uploads/2019/03/HIDROCENTRALET_NE_KOSOVE_PROBLEMET_DHE_POTENCIALI_I_TYRE_REAL_BGF_INDEP.pdf.

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