KSÜ Mühendislik Bilimleri Dergisi, 26(1), 2023
Araştırma Makalesi

KSU J Eng Sci, 26(1), 2023
Research Article

Kahramanmaras Sutcu Imam University
Journal of Engineering Sciences

Geliş Tarihi : 08.09.2022
Kabul Tarihi : 24.10.2022

Received Date :08.09.2022
Accepted Date : 24.10.2022

SEASONAL ASSESSMENT OF RUN-OF-RIVER HYDROELECTRIC POWER PLANT RAMP EVENTS

NEHİR TİPİ HİDROELEKTRİK GÜÇ SANTRALLERİNİN RAMPA OLAYLARININ MEVSİMSEL DEĞERLENDİRİLMESİ

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ABSTRACT

This study aims to seasonally examine run-of-river type hydroelectric power plants' ramp rates (generation changes) (RoRHPP). Turkey RoRHPP generations were obtained for this objective between 01 December 2020 and 01 December 2021. Obtained data are hourly resolution and belong to 560 plants. The total installed power of the plants used in work is 7897.06 MW. This study used histogram fields to examine ramp rates of 5%, 7.5%, and 10% of the installed power in 1, 3, and 6-hour periods. As a result of the investigations, the cumulative histogram areas of the ramps of 5% and above in 6 hours temporal periods of the spring, summer, autumn, and winter seasons were calculated as 39430.94, 22117.72, 17811.76, and 34914.32, respectively. When these ramps are evaluated according to their directions, the histogram areas of positive ramp (generation increase) in spring, summer, autumn, and winter are 20052.1, 10945.74, 9095.8, and 17303.19, respectively. The histogram areas of the negative ramps (reduction of generation) in spring, summer, autumn, and winter are 19378.84, 11171.98, 8715.96, and 17611.13, respectively. According to all these results, ramp events in Turkey's RoRHPP productions occurred the most in the spring. In addition, It was also concluded that positive ramp events occurred more in all seasons.

Keywords: Ramp rate, run-of-river hydroelectric power, renewable energy.

ÖZET

Bu çalışma, nehir tipi hidroelektrik santrallerinin (NHES) rampa oranlarını (üretim değişimlerini) mevsimsel olarak incelemeyi amaçlamaktadır. Bu amaçla öncelikle 01 Aralık 2020 ile 01 Aralık 2021 tarihleri arasında Türkiye NHES verileri elde edilmiştir. Elde edilen veriler saatlik çözünürlükte olup 560 tesise aittir. Çalışmada kullanılan santrallerin toplam kurulu gücü 7897,06 MW'dır. Bu çalışmada, 1, 3 ve 6 saatlik periyotlarda kurulu gücün %5, %7,5 ve %10'luk rampa oranlarını incelemek için histogram alanları kullanılmıştır. Yapılan incelemeler sonucunda ilkbahar, yaz, sonbahar ve kış mevsimlerinin 6 saatlik zaman dilimlerinde %5 ve üzerindeki rampaların kümülatif histogram alanları sırasıyla 39430.94, 22117.72, 17811.76 ve 34914.32 olarak hesaplanmıştır. Bu rampalar yönlerine göre değerlendirildiğinde ilkbahar, yaz, sonbahar ve kış aylarında pozitif rampa (jenerasyon artışı) histogram alanları sırasıyla 20052.1, 10945.74, 9095,8 ve 17303.19'dur. Negatif rampaların (üretim azalması) ilkbahar, yaz, sonbahar ve kış aylarında histogram alanları sırasıyla 19378.84, 11171.98, 8715.96 ve 17611.13'tür. Tüm bu sonuçlara göre Türkiye'nin NHES üretimlerinde rampa olayları en çok bahar mevsiminde meydana geldi. Ayrıca olumlu rampa olaylarının her mevsimde daha fazla meydana geldiği sonucuna da ulaşılmıştır.

Anahtar Kelimeler: Rampa oranı, nehir tipi hidroelektrik santrali, yenilenebilir enerji.

ToCite: KARADÖL, İ., & AVLİ FIRIŞ, F.& ŞEKKELİ, M., (2023). Seasonal Assessment Of Run-Of-Rıver Hydroelectrıc Power Plant Ramp Events. *Kahramanmaraş Sütçü İmam Üniversitesi Mühendislik Bilimleri Dergisi*, 26(1), 57-66.

INTRODUCTION

Energy production from hydroelectric power plants is standard throughout Turkey, and dam-type and run-of-river hydroelectric power plants are spread throughout the country. Many natural factors, such as the dispersion of water resources in the country, the flow rate, mountain or valley slopes, and geological conditions, determine the type of hydroelectric power plants with or without storage (river type). In addition to these natural factors, technical and financial reasons such as the purpose of use and the cost of energy transmission lines can also be decisive (Andritz Hydro, 2015; REN21, 2021). In streams with high flow, rivers on rivers, or on the branches of large streams, hydraulic energy can be utilized in-stream type power plants, generally without storage, with slope. Non-storage hydroelectric power plants use moving water resources such as streams, waves, and tides. However, the common usage area is rivers. In-stream power plants, namely run-of-river hydroelectric power plants, water is dropped onto the turbine by gaining speed with the help of a channel or tunnel without a dam or storage. The kinetic energy of the water fell on the turbine is converted into electrical energy by the turbine-generator system (Süme & Fırat, 2020).
Run-of-river hydroelectric power plants (RoRHPP) are generally small power generation power plants. In mountainous and rugged regions where it isn't easy to transport energy, river-type hydroelectric power plants provide advantages over other types of energy generation. Run-of-river hydroelectric power plants with a short construction period and low establishment cost relieve the interconnected system's load and prevent energy losses in long transmission lines (Dalcalı et al., 2012).

As of February 2022, there are 603 registered run-of-river hydroelectric power plants in Turkey (*Aylık Elektrik Üretim-Tüketim Raporları*, n.d.). The damage to the natural life of run-of-river HPPs is much less than that of storage-type HPPs. These power plants are increasing daily due to their low establishment costs, regionally applicable, and nature-friendly nature. However, the unpredictability of RoRHPP generation and the Spatio-temporal variation of generation make it challenging to integrate these resources into the grid (Kayahan, 2019; Liu et al., 2019).
A summary of the literature examining the generation variability in renewable energy sources is given in detail below; Frate et al. compared the performance of flywheels and li-ion batteries in reducing ramp rates of power produced by the wind turbine. They concluded that flywheels outperform batteries in cost (Frate et al., 2019). Different optimization methods minimize ramp events in wind power plants (Dorado-Moreno et al., 2020) and (Li & Gu, 2020). In this way, it has been concluded that ramp events seen in energy generation can be minimized. In (Kim & Kim, 2019; Martins et al., 2019; Özyön & Aydin, 2013) and (Datta, 2013), various optimization methods have been proposed to reduce the ramp events in the grid operating system. In (Chen et al., 2017) and (De La Parra et al., 2015) aims to reduce the ramp events in PV energy generation using different storage and control units. According to the literature review, studies in the field of ramp rate are generally on wind and solar energy. It has been observed that there is very little literature on Nhes production. For this reason, Turkey's RoRHPP ramp rates were investigated in this study.

This study examined ramp events of plant generations to predict seasonal changes in run-of-river hydroelectric power plant generation. For this purpose, firstly, Turkey's average RoRHPP generation was obtained in a one-year period, hourly resolution. The data obtained are divided according to seasonal periods such as spring, summer, autumn, and winter. The ramp events in the generation of the plant were examined according to their formation (negative-positive), size (5%, 7.5%, and 10% of the installed power), and frequency (frequency) in 1, 3, and 6-hour periods. The obtained results are presented in detail in the following sections.

The study consists of 4 parts. In the first part, general information about the investigation was given, and the literature reviews in this field were presented in detail. The second part presents the technical information of the dataset and RoRHPPs used in the study. In addition, the ramp ratio is defined in this section, and its mathematical equation is given. The third section shows seasonal ramp rates of RoRHPP productions in different temporal periods. In the fourth and last chapter, the results obtained in the study were interpreted, and the ramp characteristics of Turkish RoRHPP productions were obtained according to the seasons.

MATERIAL AND METHOD

Technical Overview Of RoRHPPs

The way of obtaining hydroelectric energy; is explained in two ways: by forming a dam by collecting and storing water in a pond and by using only the flow rate of streams without dams. In-stream power plants, water is dropped onto the turbine by gaining speed with the help of a channel or tunnel without a dam or storage. The kinetic energy of the water that falls on the turbine is converted into electrical energy by the turbine-generator system. Images from different perspectives of a RoRHPP are seen in Figure 1.

Figure 1. View Of The Run-Of-River Hydroelectric Power Plant From Different Angles

Turbines used in hydraulic systems can be classified according to their head, turbine output powers, the condition of the turbine shaft, the water's flow direction, and the effect of the water. Hydraulic turbines can be classified as impulse and reaction type turbines according to their intended use. Impact turbines; Pelton, Turgo, Banki type turbines are reaction type turbines; Kaplan and Francis turbines. In impact-type turbines, the blades are not in the water, and the water brought through the pipe/channel is transferred to the turbine in spraying; the turbine is operated by creating a rotational force. Reaction-type turbines rotate faster than impact turbines at the same head and flow. These turbines, which are more difficult to manufacture, are more complex than impact turbines, so they are less preferred in hydroelectric power plants with small power. Its efficiency is high in high-flow power plants and streams(Emir et al., 2014; European Small Hydropower Association - ESHA, 2004; Temiz, 2015). Since there is no water storage in river-type power plants, the production of electrical energy is produced because there is sufficient water from the river. These power plants; can work independently from the grid or in connection with the grid. Regarding the selection of turbines and generators in river-type hydroelectric power plants, Factors such as water flow, fall height, slope, size of the power plant to be established, and project installed power calculations are practical (Yıldız, 2015). The power produced in the power plants is calculated with the help of Equation 1 (Dalcalı et al., 2012).

$$P = \eta . H . Q . \gamma \tag{1}$$

In the equation, P stands for turbine power (W), η total efficiency, H head (m), Q flow rate (m^3/s) and γ specific weight of water. According to Equation 1, hydroelectric power is linearly proportional to the flow and head of the water. To evaluate the hydroelectric energy potential obtained from the water flow, it is necessary to know the changes that may occur in the water flow rate during the year and the amount of thought that can be obtained (Sangal et al., 2013).

The most determining factors in the selection of turbines used in hydroelectric power plants are the hydraulic head and, the volume per unit time, the flow rate of the water that will pass through the turbine. The speed of the turbine or generator is an essential criterion in the turbine type selection. Whether the turbine can be operated under partial flow conditions is another criterion. All turbines have power-speed and efficiency-speed characteristics. H = 1 m functional hydroelectric head and Q =1 m^3/s volumetric flow rate and selected operating cycle (n), geometrically similar to the main turbine rotor to be manufactured in the project design of the turbine. The specific speed ns of a working model turbine rotor determines the turbine dimensions. After the specified number of revolutions is determined, the turbine is designed using certain empirical formulas and ns. The specific number of revolutions can be calculated by Equation 2(Bilgili et al., 2018; Kougias et al., 2016).

$$n_s = \frac{n\sqrt{Px1.358}}{H^{5/4}} \tag{2}$$

Minimizing the speed variation between the turbine and the generator is necessary. In this, different turbine types should be used for the other heads. The speed of a turbine decreases in direct proportion to the square root of the head. For this reason, fast turbines are used in places with small heads (Özdemir, 2012). Table 1 shows the usage range of turbine types according to the hydraulic head, and Table 2 shows the specific speed values of turbine types.

Table 1. Turbine Types According To Hydraulic Head (Kougias et al., 2016)

Turbine type	Head range
Kaplan	2<H<40
Francis	10<H<350
Pelton	50<H<1300
Crossflow	3<H<250
Turgo	50<H<250

Table 2. Classification Of Turbines By Specific Speed (Kougias et al., 2016)

Turbine Type	Specific Speed (n_s)
Pelton	12-30
Turgo	20-70
Crossflow	20-80
Francis	80-400
Kaplan	340-1000

Considering the values in Table 2 for run-of-river type hydroelectric power plants, it will be appropriate to use Pelton, Turgo, and Crossflow type turbines in places with low specific speeds. Francis turbines can also be used in run-of-river type hydroelectric power plants where the speed is higher. Since the rotation speed of the turbine changes in direct proportion to the square root ratio of the height at which the water falls into the turbine, in the literature, in hydroelectric power plants below 10 meters head in general, a low head is considered, and reaction turbines are selected. It is appropriate to use impact turbines in power plants that are planned to be operated with higher heads (Mercan, 2014).

Technical Data Of RoRHPPs

Hydroelectric power plants are the most widely used renewable energy sources globally. The total hydroelectric capacity of the world is approximately 1300 GW as of 2020, and hydroelectric power plants provide 19% of the world's electrical energy (Laghari et al., 2013; Villarreal et al., 2019).

Run-of-river HEPPs have much less damage to natural life than storage-type HEPPs. The low establishment costs, regional applicability, and nature-friendly nature increase the number of such power plants daily. According to the February 2022 installed power reports received from TEIAŞ Load Dispatch Department, the total installed power of Turkey is 99890.1 MW. The total installed capacity of dam and run-of-river type hydroelectric power plants is 31502 MW, constituting 31% of the total installed power (Anon n.d.). Run-of-river type hydroelectric power plants comprise 7897.06 MW of hydroelectric energy resources and a total of 603.

The study examined seasonal ramp events of the generation of run-of-river type hydroelectric power plants. For this purpose, first of all, the entire RoRHPP generations in Turkey between 01 December 2020 and 01 December 2021 were obtained through the YEKDEM transparency platform. Obtained generation data are seasonally divided and shown in Figure 2.

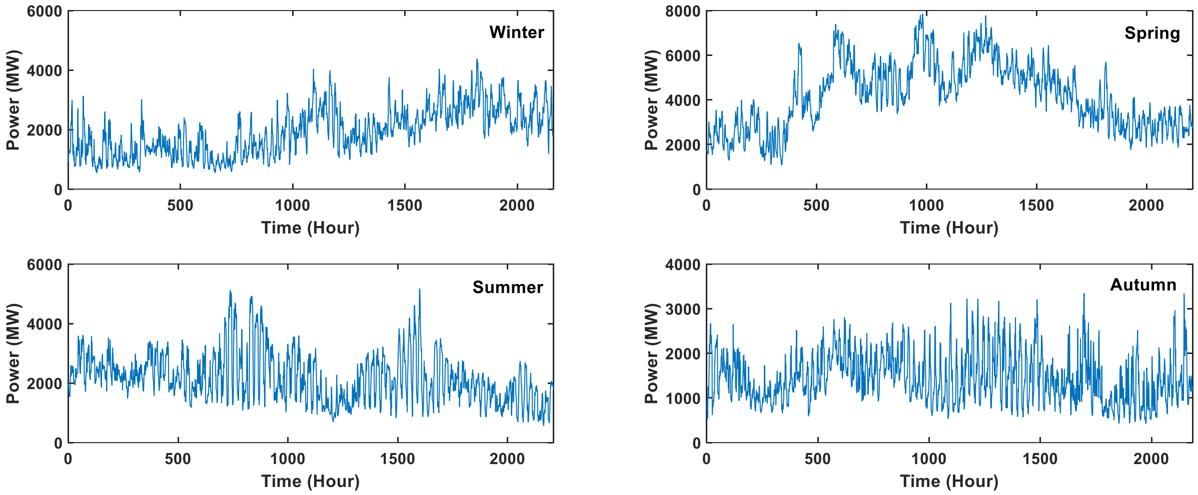

Figure 2. Seasonal RoRHPP Generation

Some statistical properties of generation data divided according to seasons are given in Table 3. According to these data, the highest average generation and standard deviation are seen in the spring season. The lowest standard deviation and middle generation occurred in the autumn season. The standard deviation in the autumn season generation is 37% of the standard deviation seen in the spring season generation. This shows that the highest generation variability occurs in the spring season. When the differences between the maximum and minimum generations in seasonal periods are examined, the differences in winter, spring, summer, and autumn are calculated as 3826.21, 6759, 4601, and 2909.6, respectively.

Table 3. Some Statistical Properties Of RoRHPP Generation Data

	Winter	**Spring**	**Summer**	**Autumn**
Standard Deviation	789.06	1482.46	821.68	552.5
Mean	1923.47	4175.33	2167.63	1450.7
Maximum	4371.82	7847.02	5167.21	3336.97
Minimum	545.61	1088.12	566.41	427.31
Time Period	01.12.2020-28.02.2021	01.03.2021-31.05.2021	01.06.2021-31.08.2021	01.09.2021-30.11.2021
Data Number	2160	2208	2208	2018
İnstalled Power	7897.06MW			

Ramp Rate

When run-of-river hydroelectric power plant generation is evaluated temporally, it is assessed that they have a variable structure (Ueckerdt et al., 2015). Different temporal periods also show other generation characteristics (Karadol et al., 2020). The high variability of RoRHPP generation over time causes many problems in terms of a grid's flexibility, security, and operating costs (Dorado-Moreno et al., 2020; Zhao et al., 2017). Because to tolerate the sudden generation increases seen in RoRHPP generation by the grid operator, online plant generation should be reduced, or methods such as load shedding are used. In opposite situations, to tolerate the instantaneous generation drops by the grid operator, online plant generation will be increased, or new plants will be used (González-Aparicio & Zucker, 2015; Teleke et al., 2010). Generation increases and decreases were seen in RoRHPP generations are defined as positive and negative ramps, respectively. However, not all generation changes are defined as ramps in the literature. For a generation change of any plant to be described as a ramp, this change must be 5% or more of the plant's installed capacity (Frate et al., 2019). The study examined the changes over 5%, 7.5%, and 10% of the total installed power to define the ramps of RoRHPP generation. The ramp size in any period of the plant generations was obtained using Equation 3 (Frate et al., 2019).

$$\Delta P_i = p(i) - p(i+t) \qquad \begin{array}{c} \Delta P = \{\Delta P_1, \Delta P_1, \dots, \Delta P_n\} \\ i = (1,2,\dots,n) \;\; n \in N \\ t = (1,3,6) \end{array} \qquad (3)$$

ΔP_i given in the equation shows the ramp size (power change amount) at the time i, $p(i)$ shows the plant generation at the i. hour, t the temporal period, and n the hourly resolution plant generation time. ΔP given in Equation 2 defines the ramp set for plant generation in all temporal periods. The characterization of ramp rates is shown in Figure 3.

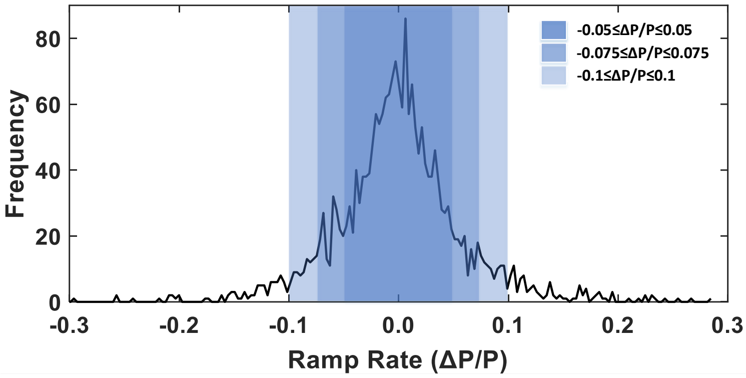

Figure 3. The Characterization Of Ramp Rates

A histogram graph of the ΔP cluster is created to determine the frequency and size of ramp events in RoRHPP generation. Cumulative ramp sizes are determined according to the seasons by calculating the areas over 5%, 7.5%, and 10% of the installed power in the histogram graphics.

RESULTS

In recent years, hydroelectric energy has had an essential share in the energy produced by renewable energy sources. Increasing energy demand and the destructive effect of traditional energy sources on the environment encourage the use of hydroelectric power. However, hydroelectric energy is divided into storable (dam) and non-storable (RoRHPP). While storable HPP generation can be controlled, RoRHPP generations cannot be controlled. Because RoRHPPs have random and unpredictable generation characteristics.For this reason, large-scale integration of RoRHPP generation into the grid causes technical and economic problems. This study investigated the formation time (season), sizes, and frequencies of RoRHPP generation ramps. As a result of the investigations, the ramp histogram graphs in 1, 3, and 6-hour periods are given in Figure 4, Figure 5, and Figure 6, respectively.

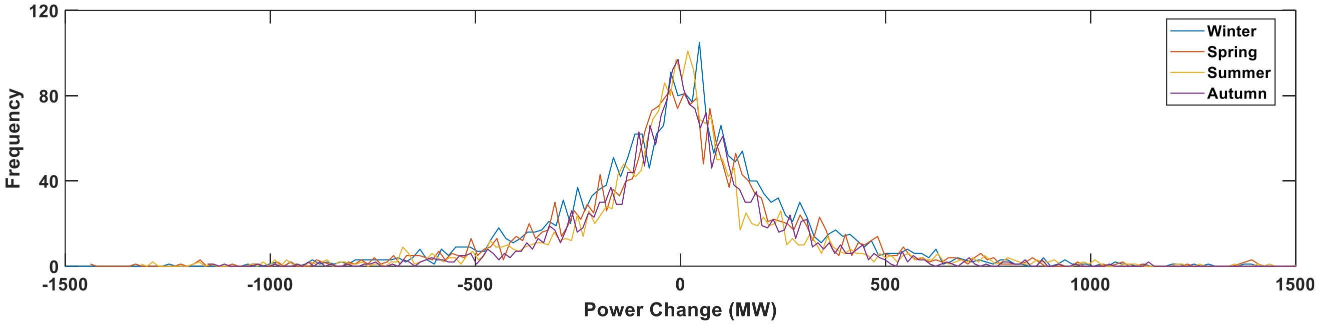

Figure 4. Histogram Of Ramp Frequencies İn A 1-Hour Period

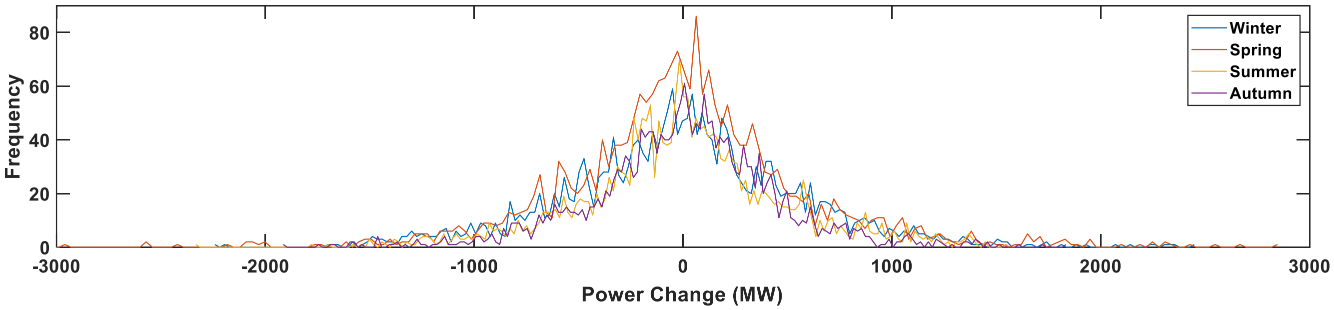

Figure 5. Histogram Of Ramp Frequencies In A 3-Hour Period

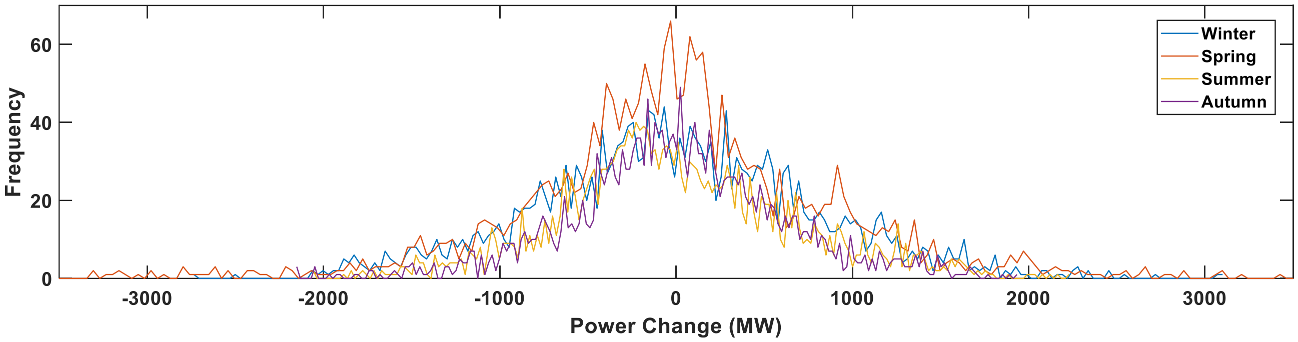

Figure 6. Histogram Of Ramp Frequencies In A 6-Hour Period

The cumulative areas of negative and positive ramps of 5% (394 MW) and above in 1, 3, and 6-hour periods are given in Table 4. According to these data, the difference between the cumulative areas of negative and positive ramps in 1 and 3-hour periods is shallow in the winter and spring seasons. However, when we evaluated for the 6 hours, the ramps with the highest cumulative area were seen in the spring season. The lowest positive and negative cumulative area was observed in autumn in the same temporal period.

Table 4. Cumulative Areas of Ramps of 5% and Above

Over 5 %	Winter		Spring		Summer		Autumn	
	Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive
1 hour	2350.45	2114.53	2029.62	2100.42	1673.51	1751.51	1051.46	990.02
3 hour	10108.24	9872.62	11655.53	10712.91	6567.92	6953.68	5516.79	5036.66
6 hour	17611.13	17303.19	19378.84	20052.1	11171.98	10945.74	8715.96	9095.8

The cumulative areas of negative and positive ramps of 7.5% (591 MW) and above in 1, 3, and 6-hour periods are given in Table 5. According to these data, the smallest negative and positive cumulative ramp areas in the 1 hour were seen in the autumn season. In the 3 and 6 hours period, the ramps with the most negative and positive cumulative areas were observed in the spring season.

Table 5. Cumulative Areas Of Ramps Of 7.5% And Above

Over 7.5%	Winter		Spring		Summer		Autumn	
	Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive
1 hour	725.23	830.08	676.54	826	730.38	907.66	279.93	355.04
3 hour	5725.65	5819.9	6957.41	6897.56	3402.65	3768.64	2636.01	2428.89
6 hour	12009.59	11950.93	13756.25	15321.11	6399.38	7541.36	5276.8	5656.64

The cumulative areas of negative and positive ramps of 10% (789 MW) and above in 1, 3, and 6-hour periods are given in Table 6. According to these data, the smallest negative and positive cumulative ramp areas in the 1 hour were seen in the autumn season. In the 3 and 6 hours period, the ramps with the most negative and positive cumulative areas were observed in the spring season.

Table 6. Cumulative Areas Of Ramps Of 10% And Above

Over 10%	Winter		Spring		Summer		Autumn	
	Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive
1 hour	209.7	375.72	291.06	291.06	304.91	347.46	116.07	95.58
3 hour	3204.47	2968.85	3441.3	4054.74	1879.37	2176.11	1167.37	1063.81
6 hour	7918.41	8109.03	9134.44	11317.97	3986.14	4998.84	2946.38	3120.9

Total cumulative areas according to different ramp sizes in different temporal periods are given in Figure 5. In the figure, blue, grey, and yellow represent the cumulative areas over a 1, 3, and 6-hour period, respectively. According to the ramp formation powers, the cumulative areas above 5%, 7.5%, and 10% are on the left, middle, and right.

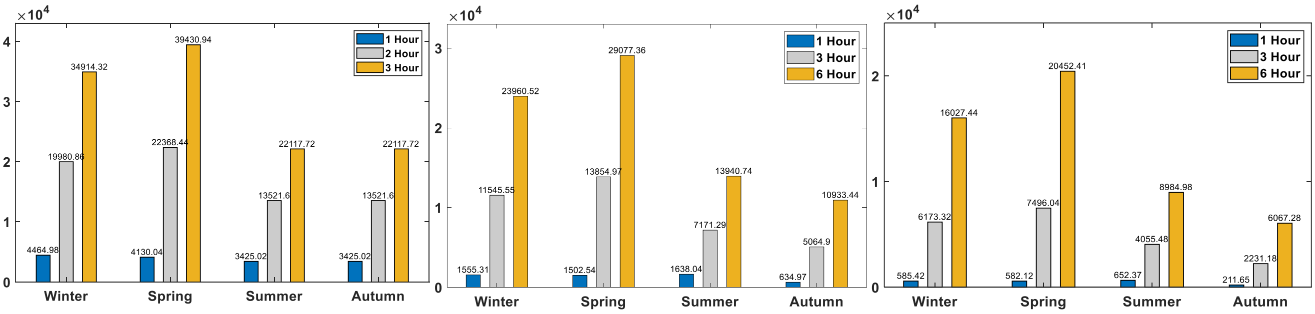

Figure 7. Total Cumulative Areas

CONCLUSION

This study aims to examine the seasonal ramp rates of the river-type hydroelectric power plant in Turkey. Because knowing the time and size of the ramps in plant generation provides excellent advantages in grid operation plans. For this purpose, the average hourly production of Turkey's 560 run-of-river hydroelectric power plants was used in the study. According to the generation of these plants, ramp events over 5%, 7.5%, and 10% compared to the installed power in 1, 3, and 6-hour periods were examined. For the investigation, 2021 plant generations were used, and these generations were evaluated seasonally. As a result of the evaluations, negative ramps are seen too much in ramp events of 5% and above compared to the installed power, while positive ramps are seen too much in ramp events over 7.5% and 10%. The lowest cumulative area in the histogram graphs of ramp events in 1-hour temporal periods was in the autumn season. The cumulative histogram area of the ramp events over 5%, 7.5%, and 10% of the installed power in 3 and 6-hour periods was seen the most in the spring season. The spring season was followed by winter, summer, and autumn seasons. According to these results, it is predicted that the effects of these resources on the grid integration can be minimized by taking precautions according to the occurrence directions, time, and size of the ramp events seen in RoRHPP generation. In further studies, hybrid optimization methods can determine plant clusters with minimum ramp events. In this way, ramp events in new plants can be minimized.

REFERENCES

Andritz Hydro. (2015). Mini compact hydro. https://www.andritz.com/resource/blob/33256/4cc3cf70a02bca500e3c8e0915b31c03/hy-mini-compact-brochure-en-data.pdf

Aylık Elektrik Üretim-Tüketim Raporları. (n.d.). Retrieved April 26, 2022, from https://www.teias.gov.tr/tr-TR/aylik-elektrik-uretim-tuketim-raporlari

Bilgili, M., Bilirgen, H., Ozbek, A., Ekinci, F., & Demirdelen, T. (2018). The role of hydropower installations for sustainable energy development in Turkey and the world. Renewable Energy, 126, 755–764. https://doi.org/10.1016/j.renene.2018.03.089

Chen, X., Du, Y., & Wen, H. (2017). Forecasting based power ramp-rate control for PV systems without energy storage. 2017 IEEE 3rd International Future Energy Electronics Conference and ECCE Asia, IFEEC - ECCE Asia 2017, 733–738. https://doi.org/10.1109/IFEEC.2017.7992130

Dalcalı, A., Çelik, E., & Arslan, S. (2012). Mikro ve mini hidroelektrik santralleri için mikrodenetleyici tabanlı mikrodenetleyici tabanlı bir elektronik governor sisteminin tasarımı. Erciyes Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 28(2), 130–135.

Datta, D. (2013). Unit commitment problem with ramp rate constraint using a binary-real-coded genetic algorithm. Applied Soft Computing Journal, 13(9), 3873–3883. https://doi.org/10.1016/j.asoc.2013.05.002

De La Parra, I., Marcos, J., García, M., & Marroyo, L. (2015). Control strategies to use the minimum energy storage requirement for PV power ramp-rate control. Solar Energy, 111, 332–343. https://doi.org/10.1016/j.solener.2014.10.038

Dorado-Moreno, M., Navarin, N., Gutiérrez, P. A., Prieto, L., Sperduti, A., Salcedo-Sanz, S., & Hervás-Martínez, C. (2020). Multi-task learning for the prediction of wind power ramp events with deep neural networks. Neural Networks, 123, 401–411. https://doi.org/10.1016/j.neunet.2019.12.017

Emir, A., Bozkuş, Z., & Yanmaz, A. M. (2014). Nehir Tipi Hidroelektrik Santrallerin Bilgisayar Destekli Ön

Tasarımı. İMO Teknik Dergi, 6925–6942.

European Small Hydropower Association - ESHA. (2004). Guide on How to Develop a Small Hydropower Plant. European Small Hydropower Association, 296. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.172.1731&rep=rep1&type=pdf

Frate, G. F., Cherubini, P., Tacconelli, C., Micangeli, A., Ferrari, L., & Desideri, U. (2019). Ramp rate abatement for wind power plants: A techno-economic analysis. Applied Energy, 254(August), 113600. https://doi.org/10.1016/j.apenergy.2019.113600

González-Aparicio, I., & Zucker, A. (2015). Impact of wind power uncertainty forecasting on the market integration of wind energy in Spain. Applied Energy, 159, 334–349. https://doi.org/10.1016/j.apenergy.2015.08.104

Karadol, İ., Yıldız, C., & Şekkeli, M. (2020). Türkiye'de RES Üretimlerindeki Rampa Olaylarının Minimize Edilmesi için Bölgesel Tesis Konumu Belirleyen Yeni Bir Optimizasyon Modeli. Gazi Üniversitesi Fen Bilimleri Dergisi Part C: Tasarım ve Teknoloji, 8(4), 959–971. https://doi.org/10.29109/gujsc.711743

Kayahan, İ. (2019). Optimal Bidding and Real-Time Operation Strategies for Wind and Pumped Hydro Storage Systems Using Stochastic Programming and Model Predictive Control. In YÖK Tez Merkezi (Vol. 8, Issue 5).

Kim, M. J., & Kim, T. S. (2019). Integration of compressed air energy storage and gas turbine to improve the ramp rate. Applied Energy, 247(April), 363–373. https://doi.org/10.1016/j.apenergy.2019.04.046

Kougias, I., Szabó, S., Monforti-Ferrario, F., Huld, T., & Bódis, K. (2016). A methodology for optimization of the complementarity between small-hydropower plants and solar PV systems. Renewable Energy, 87, 1023–1030. https://doi.org/10.1016/j.renene.2015.09.073

Laghari, J. A., Mokhlis, H., Bakar, A. H. A., & Mohammad, H. (2013). A comprehensive overview of new designs in the hydraulic, electrical equipments and controllers of mini hydro power plants making it cost effective technology. Renewable and Sustainable Energy Reviews, 20, 279–293. https://doi.org/10.1016/j.rser.2012.12.002

Li, G., & Gu, C. (2020). Economic Dispatch of Combined Heat and Power Energy Systems Using Electric Boiler to Accommodate Wind Power. IEEE Access, 8, 41288–41297. https://doi.org/10.1109/ACCESS.2020.2968583

Liu, G., Zhou, J., Jia, B., He, F., Yang, Y., & Sun, N. (2019). Advance short-term wind energy quality assessment based on instantaneous standard deviation and variogram of wind speed by a hybrid method. Applied Energy, 238(January), 643–667. https://doi.org/10.1016/j.apenergy.2019.01.105

Martins, J., Spataru, S., Sera, D., Stroe, D. I., & Lashab, A. (2019). Comparative study of ramp-rate control algorithms for PV with energy storage systems. Energies, 12(7). https://doi.org/10.3390/en12071342

Mercan, B. (2014). Orta Ölçekli Hidroelektrik Enerji Tesislerinin İncelenmesi için Örnek Bir Çalişma- Bağişli Regülatörü ve Hes. In İstanbul Teknik Üniversitesi /Enerji Enstitüsü (Vol. 1). http://www.springer.com/series/15440%0Apapers://ae99785b-2213-416d-aa7e-3a12880cc9b9/Paper/p18311

Özdemir, M. T. (2012). Çok Küçük Hidroelektrik Santrallerde Akıllı Denetleyici Destekli Aktif ve Reaktif Güç Kontrolü.

Özyön, S., & Aydin, D. (2013). Incremental artificial bee colony with local search to economic dispatch problem with ramp rate limits and prohibited operating zones. Energy Conversion and Management, 65, 397–407. https://doi.org/10.1016/j.enconman.2012.07.005

REN21. (2021). Renewables 2021 Global Status Report. In Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector. https://www.ren21.net/wp-content/uploads/2019/05/gsr_2020_full_report_en.pdf%0Ahttp://www.ren21.net/ resources/publications/

Sangal, S., Garg, A., & Kumar, D. (2013). Review of Optimal Selection of Turbines for Hydroelectric Projects. Review of Optimal Selection of Turbines for Hydroelectric Projects, 3(3), 424–430.

Süme, V., & Fırat, S. S. (2020). Hidroelektrik Santraller ve Rize İlinde Bulunan Hidroelektrik Santrallerin Şehir ve Doğu Karadeniz Havzası İçin Önemi. Türk Hidrolik Dergisi, 1–15.

Teleke, S., Baran, M. E., Bhattacharya, S., & Huang, A. (2010). Validation of battery energy storage control for wind farm dispatching. IEEE PES General Meeting, PES 2010, 24(3), 725–732. https://doi.org/10.1109/PES.2010.5589640

Temiz, A. (2015). Nehir Tipi Hidroelektrik Enerji Santrali Uygulamaları. In III. Enerji Verimliliği Günleri.

Ueckerdt, F., Brecha, R., & Luderer, G. (2015). Analyzing major challenges of wind and solar variability in power systems. Renewable Energy, 81, 1–10. https://doi.org/10.1016/j.renene.2015.03.002

Villarreal, J. L. S., Avalos, P. G., Galvan Gonzalez, S. R., & Dominguez Mota, F. J. (2019). Estimate electrical potential of municipal wastewater through a micro-hydroelectric plant. 2018 IEEE International Autumn Meeting on Power, Electronics and Computing, ROPEC 2018, Ropec, 7–12. https://doi.org/10.1109/ROPEC.2018.8661411

Yıldız, V. (2015). Numerical simulation model of run of river hydropower plants: concepts, numerical modeling, turbine system and selection, and design optimization.

Zhao, J., Abedi, S., He, M., Du, P., Sharma, S., & Blevins, B. (2017). Quantifying Risk of Wind Power Ramps in ERCOT. IEEE Transactions on Power Systems, 32(6), 4970–4971. https://doi.org/10.1109/TPWRS.2017.2678761