THE ASSESSMENT OF THE OPERATIONAL ENERGY PERFORMANCE OF THE HYDROPOWER UNITS FROM THE DRAGAN-IAD

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Abstract: This work aims to study the performances of the hydro aggregates in the Drăgan-Iad Development, focusing on determining the performances in order to make them more efficient.
The objective of the tests was to evaluate the real possibilities of operation of hydro aggregates equipped with Francis turbines, in primary and secondary regulation regimes. For this purpose, the hydro aggregates from CHE Remeți, as well as the hydro aggregates from CHE Munteni, were subjected to some testing, which implies taking some data from the system, as well as electrical and mechanical measurements from the field, in order to use them for system services.[In the first part of the work, the essential characteristics of the Dragan-Iad Development [ADI] and the related hydro-units [AHE] are presented. The second part is dedicated to the presentation of the work methodology, in the third part the results obtained are highlighted, and in the final part they are presented research conclusions

Keywords: hydro generator, turbine, tests, performances

1. INTRODUCTION

The power plants within the AHE in ADI are equipped with vertical type hydro aggregates,the generator is of the synchronous type and is directly and rigidly coupled with a Francis type hydraulic turbine, the assembly forming an aggregate with three bearings: the radial bearing of the turbine, a radial bearing mounted in the lower star of the generator and a combined radial-axial bearing mounted in the upper star of the generator [6],[7],[8],[9].

The generator is cooled by air in a closed circuit. The ventilation air is cooled by means of heat exchangers (air coolers), placed on the generator housing. The cooling agent is water.

The power plants within the AHE process the water from the Dragan reservoir.

Normal operation of the AHE is considered its operation with the hydraulic machine in turbine mode and the electric machine in generator mode with automatic speed regulation and automatic operation control when all its protections are in operation.

Normal operating conditions [11]:

The normal operation of the turbine is considered to be its operation with the hydraulic machine in turbine mode and the electrical machine in generator mode with automatic speed adjustment and automatic operation control when all its protections are in operation.

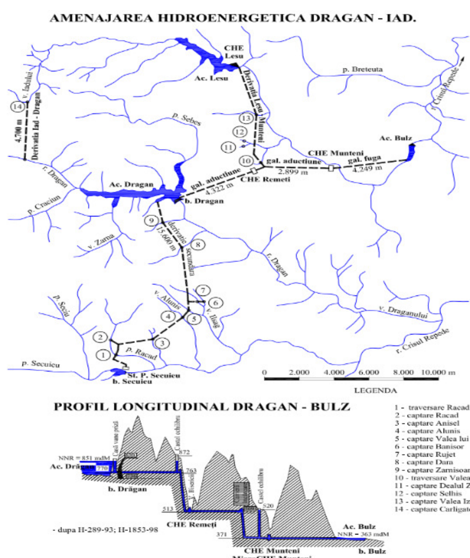

Fig.1 - Hydropower plant Drăgan - Iad[11]

The characteristic parameters of the installation are:

- drops within normal limits: 27,6 bar operation with two hydropower units, respectively 26,6 bar. operation with a hydropower unit;
- ambient temperature at the turbin level at least 10ºC;
- the automatic speed regulator in operation;
- stroke transducers mounted on the AD servomotor in operation;
- the water level in the turbine cover detected by the level relays should be within normal limits, 0-300mm;
- the pressure in the GUP accumulator is maintained within the limits of 36-40 bar;
- the oil level in the GUP accumulator is detected by the level relays and must be between a minimum and a maximum level;

- the oil temperature in the GUP tank must be higher than 10ºC;
- the oil level in the turbine bearing detected by the level relay should be normal, between -20mm and +20mm;
- the turbine bearing temperature less than 650 C. notified by the turbine bearing's thermal control resistors.

Table 1. Installed power and energy production year AHE Drăgan-Iad

2.

Hydroelectric plan [CHE]	Installed capacity [MW]	Hydro [HPP]		Energy productin year/enviroment Hidrologic [GWh]
		Tip generator	Tip turbyne	
HPP Remeti	100	Sincron	Verticala tip Francis	200
HPP Munteni I	50	Sincron	Verticala tip Francis	120
CHEMP Munteni II	0,630	Sincron	Orizontala de tip Francis	2
CHEMP Leșu	3,4	Sincron	Verticala tip Francis	6,4

WORKING METHODOLOGY

In order to obtain a maximum production of electricity, it is necessary for a CHP to operate at optimal parameters. This means an operation of hydro aggregates at maximum efficiency and with minimal load losses in the production process. Through the method of calculating the quantities obtained in AHE, it is aimed to reach the functional parameters specific to the production of electricity [1],[12],[13],[14], respectively:

• The operation of the hydroaggregate at the imposed parameters, which will create a water stock that will be available for the realization of an additional production of electricity through its turbine;
• Solving the problem related to the optimization in operation of the hydro units in

a power plant, is done by identifying the operating characteristics and their work limitations;
• Knowledge of the yield variation curves in relation to the turbine head and flow rate, as well as the knowledge of the load loss variation in relation to the turbine head and flow rate.
• Knowing the variation curves of the efficiency in relation to the drop and the flow of the turbine, as well as knowing the variation of the load losses in relation to the drop and the flow of the turbine.

Optimizarea CHE cu o cadere mare are semnificatia producerii unei puteri cerute de catre dispecerul energetic, cu pierderi minim and with minimal water consumption. The water from the reservoir is brought to the turbines through a system of galleries, the turbines driving the generator. The obtained theoretical power of the AHE is not completely transformed into electric power, being inevitable hydraulic losses in the supply pipe, in the forced pipe, the spiral chamber and the turbine as well as electrical losses in the generator[6],[15].

$$PT = g\rho HQ \qquad (1)$$

where:
-g gravitational acceleration
-ρ water density
- H caderea
-Q debitul turbinei

Pierderile hidraulice ΔP_n se pot exprima ca reducere a caderii nete a turbinei [5];
Aplicand relatia de calcul ΔP_n :

$$\Delta P\_n = KQ2 \qquad (2)$$

where: K- is the loss coefficent

The net fall is determined for each section, applying the following calculation relationships:

$$H_n = \left(\frac{p_i}{\gamma} + \frac{v_i^2}{2g} + z_i\right) - \left(\frac{p_e}{\gamma} + \frac{v_e^2}{2g} + z_e\right) \qquad (3)$$

The following calculus relation for HU apply:
Net drop

$$H_n = z_i - z_e + \frac{Q^2}{2g}\left(\frac{1}{S_i^2} - \frac{1}{S_e^2}\right) + \frac{p_i}{\gamma} - \frac{p_e}{\gamma} \qquad (4)$$

and

$$H_n = z_i - z_e + 15{,}86708 \cdot 10^{-3} \cdot Q^2 + \frac{p_i}{\gamma} - \frac{p_e}{\gamma} \qquad (5)$$

where: z_i is the upstream level in the entrance section of the spiral chamber;
z_e, the downstream level in the outlet section of the suction tube;
S_i, the entrance section of the turbine;
S_e, the outlet section of the turbine.

- The wffective hydraulic power of the turbine;

$$P_h = \rho \cdot g \cdot H_n \cdot Q \cdot \eta_h = \frac{P_A}{\eta_G} \qquad (6)$$

- Index flow rate;

$$Q_i = \frac{P_{he}}{\rho \cdot g \cdot H_n \cdot \eta_h} \qquad (7)$$

- Efficiency turbine;

$$\eta_T = \eta_h = \frac{P_{he}}{\rho \cdot g \cdot H_n Q_i} \qquad (8)$$

- efficiency aggregate;

$$\eta_A = \eta_T \cdot \eta_G \quad (9)$$

where:
η_T is the efficiency of the turbine;
η_G is the efficiency of the generator.

3. OBTAINED RESULTS

Considering the fact that the hydro aggregates of the Remeți CHE and the Munteni CHE were put into operation in the years 1985-1992, these hydro aggregates have a lifetime of at least 40-50 years, with an average annual operating time of at least 2000 hours/year and with a number of 730 starts per year. Under these conditions, the need for a periodic evaluation of the operating state is imposed by performing performance tests, measuring the operating parameters

Measurements were made of the main characteristic quantities at the powers:

5,5 MW, 12 MW, 20 MW, 25 MW, 30 MW, 35 MW, 40 MW, 44 MW.

3.1. Measured and calculated quantities for water aggregates 1 and 2 from the HPP Remeți

The measured sizes and the calculed sizes can be found in tables 2-5 , as well amn in the graphic representation in fig.2 si fig.3.

The transposition of the obtained results into graphs highlights the difference between the four calculated quantities, η_T- turbine yield and η_A- aggregate yield, as well as the difference between P_T - turbine power and

P_A - aggregate power and a0 which represents the opening of the guide blades.

Tabelul.2. Measured sizes HA1-HPP Remeti

a_0 [mm]	Q [m^3/s]	H_n [m]	η_G [%]
22.816	4.469	308.944	94.228
32.468	6.773	308.674	95.540
42.802	9.137	308.612	96.581
50.821	10.916	306.911	97.125
55.143	12.045	306.000	97.353
62.971	14.094	305.588	97.608
71.458	15.624	304.596	97.656

Tabelul.3 Calculated sizes HA1-HPP Remeti

I_m [A]	$P_{G\,m}$ [MW]	$p_{Am\,m}$ [bar]	$S_{AD\,m}$ [mm]
442.876	5.321	30.844	35.416
767.587	12.781	30.782	50.397
1420.227	20.643	30.722	66.438
1482.886	26.438	30.519	78.896
1742.219	29.786	30.399	85.619
2002.191	36.002	30.286	97.810
2346.528	39.941	30.136	111.060

Tabelul.4. Measured sizes HA2- HPP Remeti

I_m [A]	$P_{G\,m}$ [MW]	$p_{Am\,m}$ [bar]	$S_{AD\,m}$ [mm]
298.2031	4.655196	14.50537	79.08281
645.8217	5.12459	14.35934	89.18379
710.767	5.107819	14.35955	89.18355
522.4824	9.141879	14.32226	124.5866
526.1366	9.15099	14.3237	124.59
954.2336	13.05941	14.26545	150.6321
790.865	13.10854	14.2682	150.6227

Tabelul.5 Calculated sizes HA2- HPP Remeti

a_0 [mm]	Q [m^3/s]	H_n [m]	$\square_G$ [%]
20.242	4.490	306.953	94.324
20.238	4.564	306.969	94.332
33.923	7.085	307.152	95.469
33.924	7.073	307.227	95.471
45.057	9.867	306.826	96.624
45.059	9.863	306.773	96.623
49.446	11.378	307.016	97.045

Based on the obtained results, the graphs fig.2 and fig.3 could be created. The tests for HA1 were performed in the power range 5÷40 MW, and for HA2, the power range at which the tests were performed between 5,8 ÷ 44 MW. Each measurement point in table 2, table 4. Represents the arithmetic mean of 200 points acquired in 200 seconds. [3]

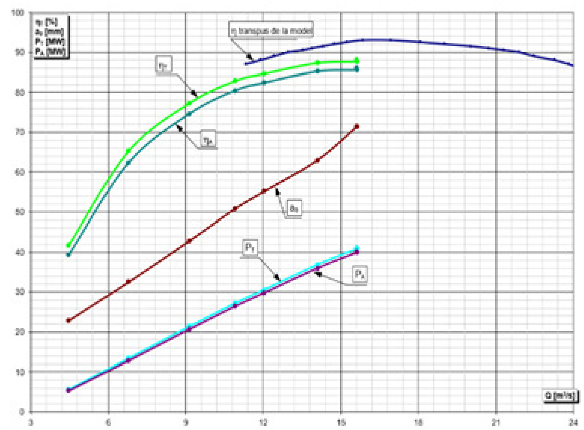

Fig.2. Graph HA1 HPP Remeti

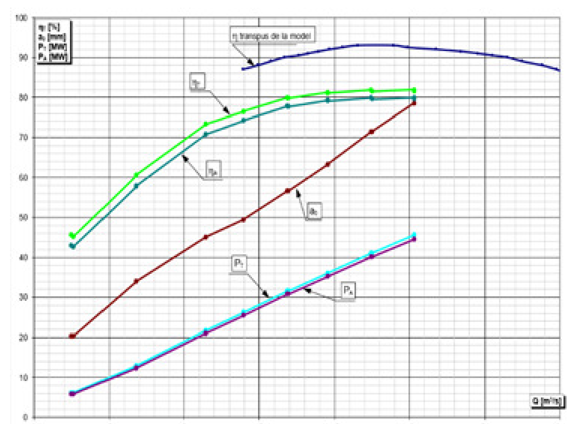

Fig.3. Graph HA2 HPP Remeti

Following the measurements between the stroke of the servo motor of the steering device, S_{AD} and the opening of the steering vanes a_0, transposed in the graph below fig. 4, it is observed that $a_0 = f(S_{AD})$, wich means that the hydraulic power of the turbine (P_T) is equal to the aggregate power (P_A).

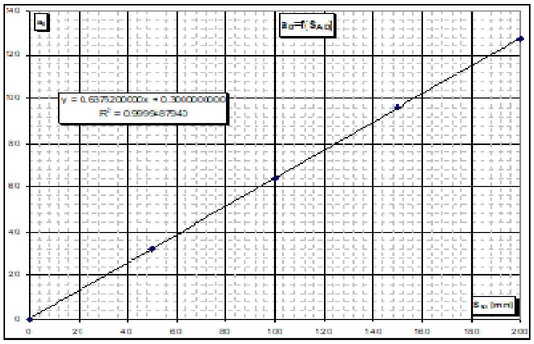

Fig. 4 Characteristic $a_0 = f(S_{AD})$, b – Obtained results for the case HPP Remeți, S_{AD}=servomotor

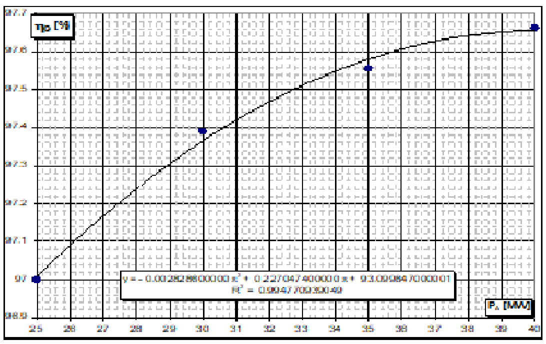

Fig. 5. The efficiency of the generator from the FPP Remeti

stroke of the steering device; a0med = opening of the guiding vanes.
In the calculation -fig.5. [11]

3.2. Measured and calculated quantities for water aggregates 1 si 2 from the FPP Munteni

Applyng the calculation relations presented above, the results shown in the following tables and graphs are obtained.

Tabelul.6 Measured sizes HA1-HPP Munteni

I_m	$P_{G\,m}$	$p_{SAD\,m}$	$p_{Am\,m}$	$S_{AD\,m}$
[A]	[MW]	[bar]	[bar]	[mm]
481.3666	5.244293	16.53519	14.35883	88.90233
667.6596	5.21228	16.33746	14.36149	88.9063
648.5984	9.475059	20.20227	14.31225	126.0674
542.3188	9.51761	19.78462	14.32011	126.0616
814.4125	13.12866	20.72959	14.26569	149.2307
959.7519	13.09398	21.86972	14.26267	149.2445
1001.769	17.00659	18.28277	14.263	170.1797

Tabelul.7 Calculated sizes HA1-HPP Munteni

a_0	Q	H_n	□G	P_T	□T	□A
[mm]	[m³/s]	[m]	[%]	[MW]	[%]	[%]
35.676	7.406	134.24	93.89	5.585	57.31	53.81
35.678	7.408	134.26	93.89	5.552	56.95	53.46
52.416	9.918	134.15	95.87	9.883	75.74	72.62
52.413	9.932	134.22	95.89	9.926	75.92	72.80
64.456	12.281	134.16	96.82	13.560	83.92	81.25
64.464	12.301	134.14	96.81	13.525	83.59	80.92
76.408	15.198	135.16	97.34	17.470	86.72	84.42

Tabelul.8. Measured sizes HA2-HPP Munteni

I_m	$P_{G\,m}$	$p_{Am\,m}$	$S_{AD\,m}$
[A]	[MW]	[bar]	[mm]
298.2031	4.655196	14.50537	79.08281
645.8217	5.12459	14.35934	89.18379
710.767	5.107819	14.35955	89.18355
522.4824	9.141879	14.32226	124.5866
526.1366	9.15099	14.3237	124.59
954.2336	13.05941	14.26545	150.6321
790.865	13.10854	14.2682	150.6227

Tabelul.9. Calculated sizes HA2-HPP Munteni

a_0	Q	H_n	η_G	P_T	η_T	η_A
[mm]	[m³/s]	[m]	[%]	[MW]	[%]	[%]
31.78	6.760	136.36	93.52	4.978	55.06	51.50
35.79	6.943	134.16	93.82	5.462	59.81	56.125
35.79	6.951	134.17	93.81	5.445	59.56	55.88
51.68	9.689	134.10	95.75	9.547	74.92	71.74
51.69	9.694	134.12	95.76	9.556	74.95	71.77
65.22	12.48	133.93	96.80	13.49	82.30	79.67
65.21	12.51	133.948	96.817	13.540	82.366	79.744

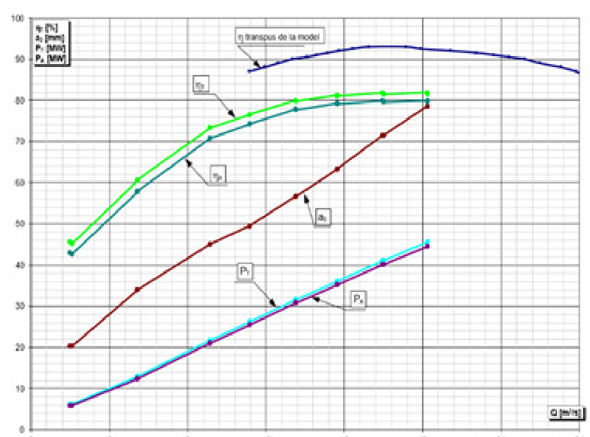

Fig.6. Gaph HA1 FPP Munteni

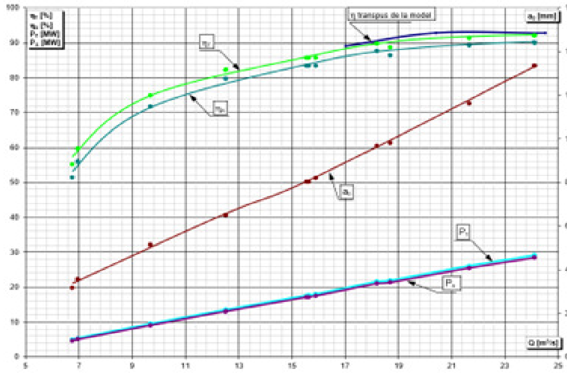

Fig.7. Graph HA2 FPP Munteni

The sizes analzed in fig.6 differ from those shown fig.7, it can be observed in the first frame a decline in η_T si η_A, as weel a difference between P_T si P_A . [3]

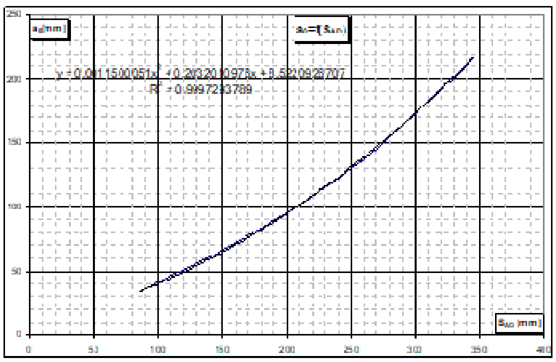

Fig.8. The results obtained for FPP Remeți:

Characteristic a0 = f(SAD), SAD= steering gear ervomotor stroke; a0med= opening of the guiding vanes.

. In the calculations, the yield determined by tests was used and it is presented as a function of the active power at the generator terminals -fig.9. [11]

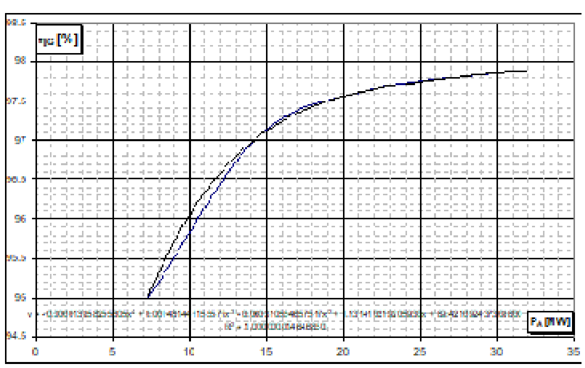

Fig. 9 The efficiency of the generator from the -FPP Munteni

3.3. Determination of power limits for hydro aggregates from FPP Remeți

After determining the power values for the maximum operating regime, the graphicevolution over time of the characteristic quantities in this the characteristic quantities in this operating regime in presented [fig.10 and fig.11] witch charge for HA1 it is PA = 47,86 MW HA1 , and for HA2 , PA = 37,43 MW.

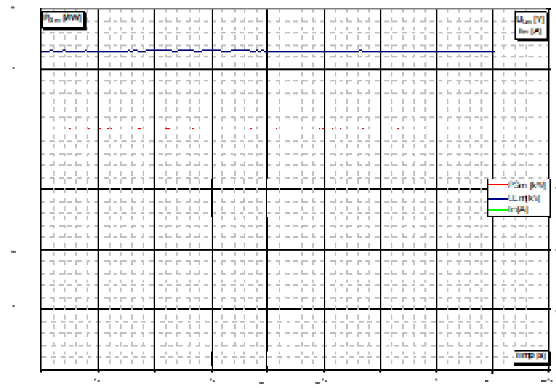

Fig. 10.The time evolution of the caracteristic sizes for HA1-FPP Remeti

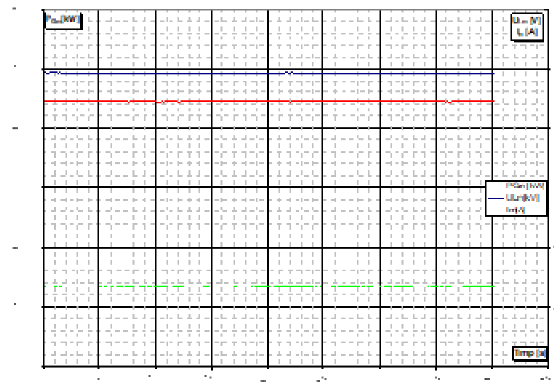

Fig. 11.The time evolution of the caracteristic sizes for HA2-CHE Remeti

The minimum power achieved for the hydro unit nr.1 was PG=5,321 MW. În the fig.12, a comparison between the quantities measured at the minimum power achieved is presented graphically and the immediately hight power level (PG =12,78 MW) where they performed the measurements. The minimum power at which the hydro unit was loaded no. 2 it is PG = 5,815 MW. The next step of power achieved was PG = 12,33 MW. In the fig.13 shows the comparison between the values measured for these two powers.

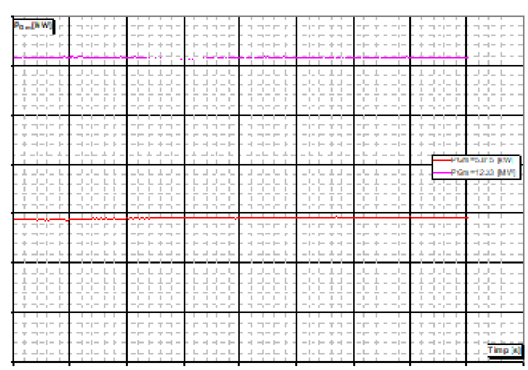

Fig. 12. The time evolution of the active power at the terminals HA1-FPP Remeti at two load levels.

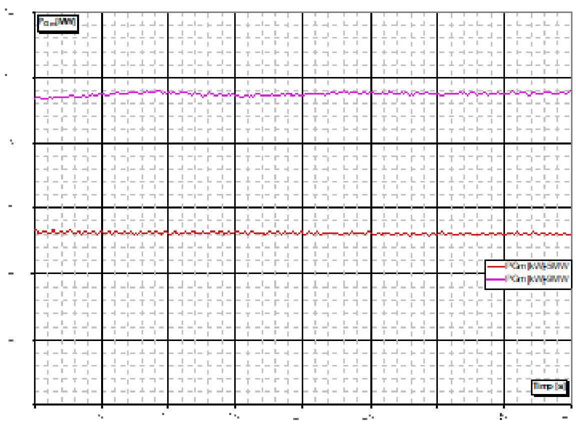

Fig. 13. Evolutia in timp a puterii active la bornele HA2-FPP Remeti la doua trepte de sarcina

3.3. Determination of power limits for hydro aggregates from-FPP Munteni

Afrer determining the power values for the maximum operating regime, the graphic evolution in presented ,in time of the characteristic size in tis operating mode [fig.14 and fig.15] for witch the charge for HA1 it is P_A = 19,83 MW HA1 , and for HA2 , P_A = 20,34 MW impact. For example, to obtain environmentally friendly hydrogen, manufacturing costs may be higher than in the case of more polluting technologies that are cheaper.

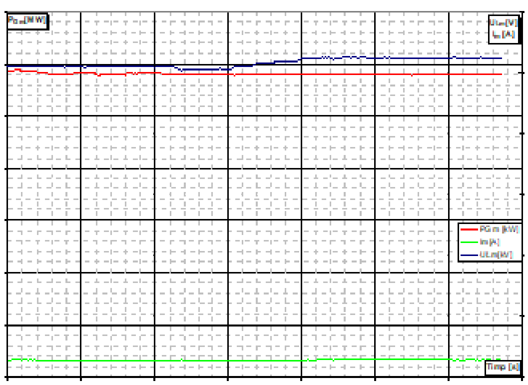

Fig. 14.Time evolution of characteristic suzes for HA1-PFF Munteni

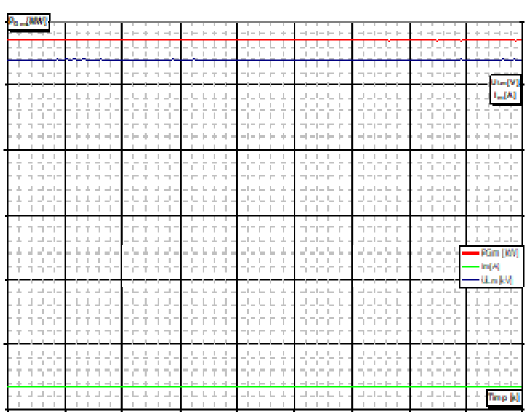

Fig. 15.Time evolution of characteristic suzes for pentru HA2-PFF Munteni

The minimum power achieved for the hydro unit nr.1 was **P_G= 5,228 MW**, in (fig.15) a comparison between the two test sizes is presented graphically, respectively for the test of hydro aggregate no. 2 with a loading power **P_G = 5,116 MW.** The next power stage made for comparison being P_G = 9,146 MW. The minimum power at which the hydro aggregate no. 2 was loaded is **P_G = 5,116 MW.** The next step of power achieved was P_G = 9,146 MW.

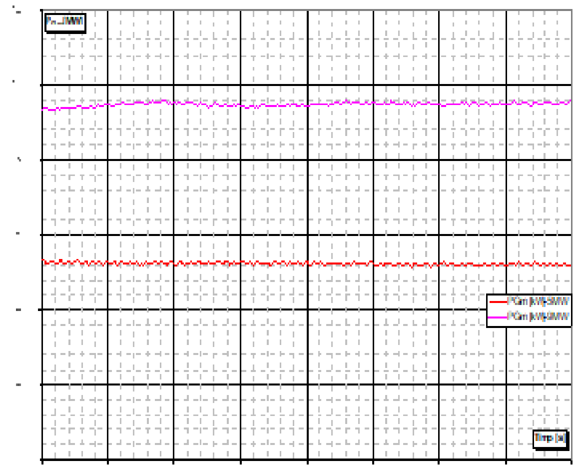

Fig. 16. The active power at the generator terminals as a function of time at the measured minimum powers HA1-FPP Munteni

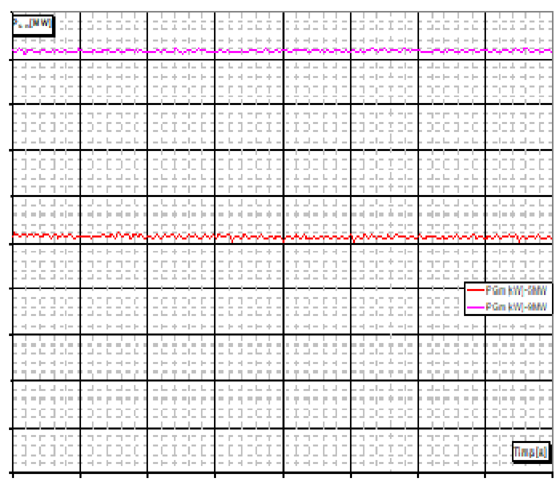

Fig. 17. The active power at the generator terminals as a function of time at the measured minimum powers HA2-PFF Munteni

3.5.Turbine operation diagram from CHE Remeti and CHE Munteni

Is drawn based on the results obtained and presented in the cha.2,3. The model of the turbine operating diagram (DET) is according to international standards, IEC 199[10], which takes into account yhe norms by which the performances of hydraulic machines are determined. In the fig.18 introduces himself DET for francis type hydraulic turbine Francis.

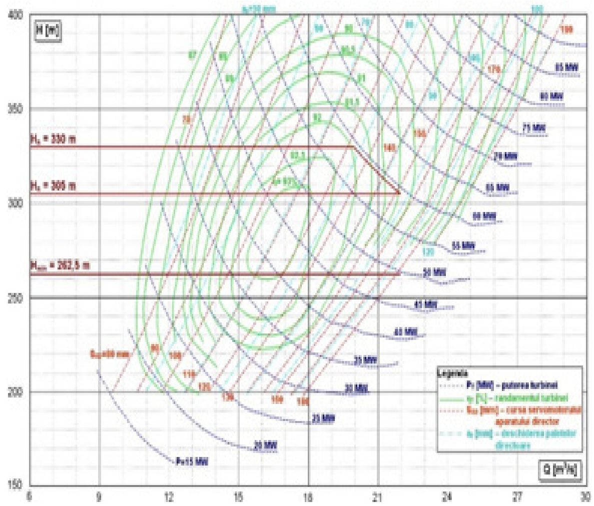

Figura 18. Turbine operation diagram from CHE Munteni and CHE Remeti

4. CONCLUSIONS

Hydropower units (AHE) subject to analysis they are part of a complex hydropower arrangement, with a lifespam of over 36 year , with a large number of operating hours (over 2000 hours a year) and an appreciable number of stops (close 400 hours /year), depending on the checks carred out annually and the events caused by accidental stops.

The maximum powers given by the manufacturer for each hydro aggregate from CHE Remeti, is 50 MW, the maximum power as witch the groups can operate from CHE Remeti, is 95,7% for hydro aggregates no.1 and 74,8% for hydro aggregates no.2 due to the operating restrictions resulting from the operation of the generators until now. At these powers, the two hydro aggregates behave stably from the point of view of the regulation system.

The characteristic sizes of the generators for the two hydro aggregates at the minimum load values do not show oscillation and pulsations;

The strokes the servomotors of the steering devices and the pressures in the servomotors of the steering devices have a stabile evolution for the load range in witch the tested HA operate.

Pressure pulsations in the spiral chamber measured with the differential transducer mounted on the sockets Winter – Kennedy they are triple at the lowest powers achieved on the groups, compared to the immediately higher power step.[11]

It is considered that HA2-FPP Remeti they cannot be operated at the maximum capacity given by the manufacturer, due to pronounced wear and tear, having more than 30 years of operation.

The maximum powers given by the manufacturer for each hydro aggregate in the FPP Munteni, is 25 MW, and the maximum power at which the groups can operate from FPP Remeti, is 7,94% from hydro aggregates no.1 and 81,36% from hydro aggregates no.2 due to operating restrictions, having over 35 years of operation.

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