REVIEW OF TURBINE GOVERNING SYSTEM TESTS PERFORMED ON HYDRO-POWER PLANTS IN CROATIA

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Abstract

This paper reviews different measurement methods of dynamic parameters in hydro-power turbine governing system. Twenty years of developing and maintaining such systems allow our experts to do diagnostics of a developing fault before its actual occurrence. Significant amount of collected data enabled a comparative analysis with very interesting results. Measurements made by integrated applications will be presented here alongside regular tests. The most valuable benefit of all described efforts is energy production without unpredicted breaks.

Keywords

Measurements, turbine, regulator, dynamic, parameters

1 Introduction

In order to ensure safety and increase operational performance and reliability of a complex system, such is a hydro-power plant, periodical tests should be performed. The testing procedure is defined by the set of standards [1] [2] and codes [3] that requires actual information about the dynamic parameters of the turbine system. Adequate provision for testing should be ensured through the phase of plant design. Appropriate conditions are elementary requirement for easy and affordable tests that guarantee long and healthy lifetime of the system.

The choice of sensory system and data acquisition (DAQ) depends on the plant. There are three basic approaches as shown in Figure 1:

1. standalone, completely independent measurement system added to the observed system while testing
2. combined system that uses data from the digital regulator with pre-calibration and some additional sensors
3. transient recorder, integrated in the system with the main purpose of the post-failure diagnostics [4]

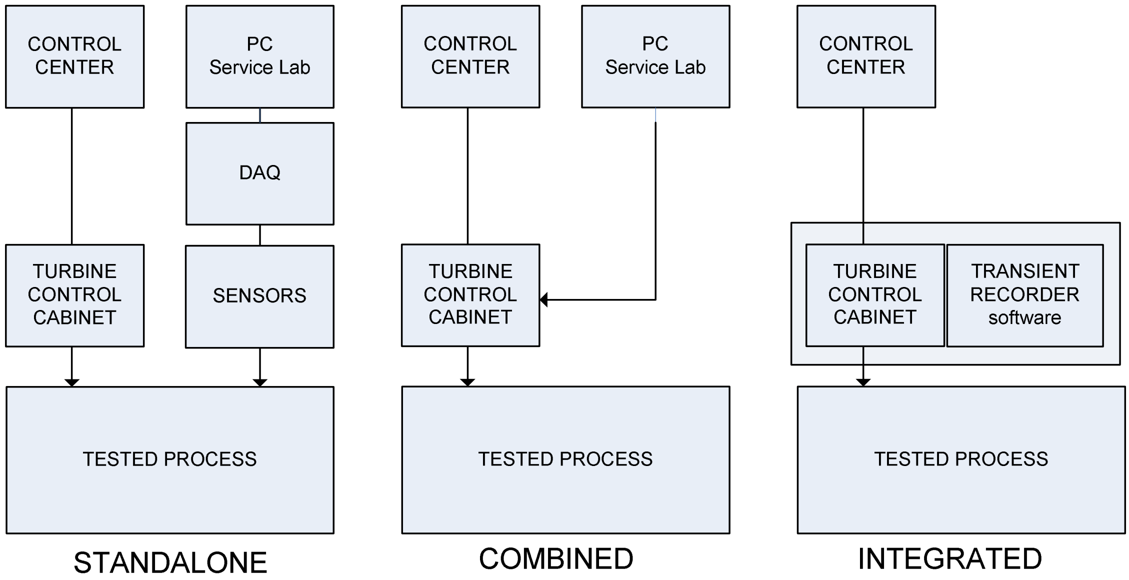

Figure 1: Block schematics of three different testing approaches

The first option is used when testing older or protected systems that don't allow any connections [5]. All measuring equipment is required to be set just for testing purpose. Placing sensors, arraying cables, setting the adjustment circuits etc. may be costly in both time and money, a clear disadvantage. The most common approach is the second one, with combined configuration where existing infrastructure is used. Each sensor must be tested individually and calibrated if needed. Setting up the software for data collection is a bit different than in standalone configuration: digital addresses of relevant variables from the turbine control system should be known. The integrated approach is a new product, very similar to the combined system, but it does not require PC and enables recordings of transient events even in every-day working mode. Transient recorder is triggered manually or automatically as response on some specific event like emergency stop or initial start. The examples of such approach may be seen in HPP Lešće, HPP Čakovac, HPP Dubrovnik, HPP Senj, HPP Đale etc.

2 Turbine tests

The scope of this paper is testing functions and components of basic primary modes of hydro control systems: speed, power and opening control. The output of each segment has common elements: reference values, actual values and additional auxiliary values such as limiters and disturbance parameters. Thanks to the Institute's expertise as a national leader in turbine governing systems, as described in [6] [7] [8] and [9], our engineers have the privilege to test and analyze most of high power hydro turbines in Croatia [10]. Due to limited space, only a selection of the performed tests will be mentioned here. Choosing from portfolio spanning 20 years was a very demanding task. At the end, geographical and technical characteristics became main guideline for the selection. Chosen turbine systems with their basic parameters are listed in Table 1.

Table 1: Characteristics of the tested HPP turbines shown in this paper

POWER PLANT	Type	Unit	P [MW]	Design head [m]	Rated discharge [m^3/s]	Rated rotation sped [o/min]	Constr-uction year	Testing approach
HPP Varaždin	Kaplan	A	47	21.9	225	125	1975	1
PSPP Velebit	single-stage turbine-pump	A	138	turbine 517 pump 559	turbine 30 pump 20	600	1984	2
HPP Rijeka	Francis	A	18.4	212.7	10.5	600	1968	1
HPP Peruća	Francis	A	30	47	60	187.5	2005	2
HPP Đale	Kaplan	A	20.4	21	110	166.6	1989	1/2

This paper will try to point out the significance of performing qualitative testing through the examples of the real power generating systems. Analyzed data were collected periodically and two of three mentioned testing approaches were used. By comparing the turbine's behavior in the same experiment performed in different years, this review will track changes through time. Different tests are usually performed with different settings or with different plant components, since the aged equipment is regularly replaced during the plant maintenance. Therefore, differences recorded in different years do not reflect equipment aging, but show differences in the plant control system setup. This paper will exclude all the details and will concentrate just on existence of difference and hint some possible causes.

2.1 Opening control

The role of the opening control is to position the servomotor, usually as a follow-up control in master control operations. A special design of servo opening systems implemented on PSPP Velebit includes the group of servomotors, linked all together, guiding the wicket gates to a desired position. Such electro hydraulic control requires very precise synchronization. The closing and opening movements of the servomotors are not continuous but take place in 2 or more speed steps. Opening and closing speed rates are defined by the manufacturer, so there is no purpose to directly compare behavior of different opening control systems. Pressure variations are not subject of this paper, but it is worth to mention that the safety testing procedures should be done if some boundary values are exceeded.

2.2 Speed control

Speed control of the turbine is tested while starting, stopping and in steady-state conditions in mechanical run. Turbine startup is the most interesting because its behavior is unique from system to system. While starting, the speed curve is mainly determined by the characteristics of the installation, such as the unit acceleration constant, the allowable gate opening rates etc. The speed governor is turning on when approximately 80% of rated speed is reached ($t_{0.8}$). The main objective of this phase is to reach synchronization readiness within an acceptable time span. Synchronization readiness is achieved when the speed change rate dx/dt does not exceed a given value within the synchronization band. According to [2] recommended values for synchronization band are from 0.995 to 1.01 of the rated speed. Speed change rate for synchronization is $dx/dt = 0.003\ s^{-1}$. The ratio between time at which the generator is switched on line and startup time $t_{0.8}$ should be in range from 1.5 to 5. The fluctuation of the turbine speed shall not exceed the speed limit of 0.1% for measurements under steady-state conditions, except if permitted by mutual agreement.

Figures 2 to 6 represent speed control at turbine startup of different governing systems during different periodical tests. Figure 7 shows the speed curves recorded at five different plants. Curves are matched together to fit as much as possible. Almost every test of this system took place after annual system maintenance. Different settings caused some deviations from year to year, but all curves are still within pre-defined boundaries.

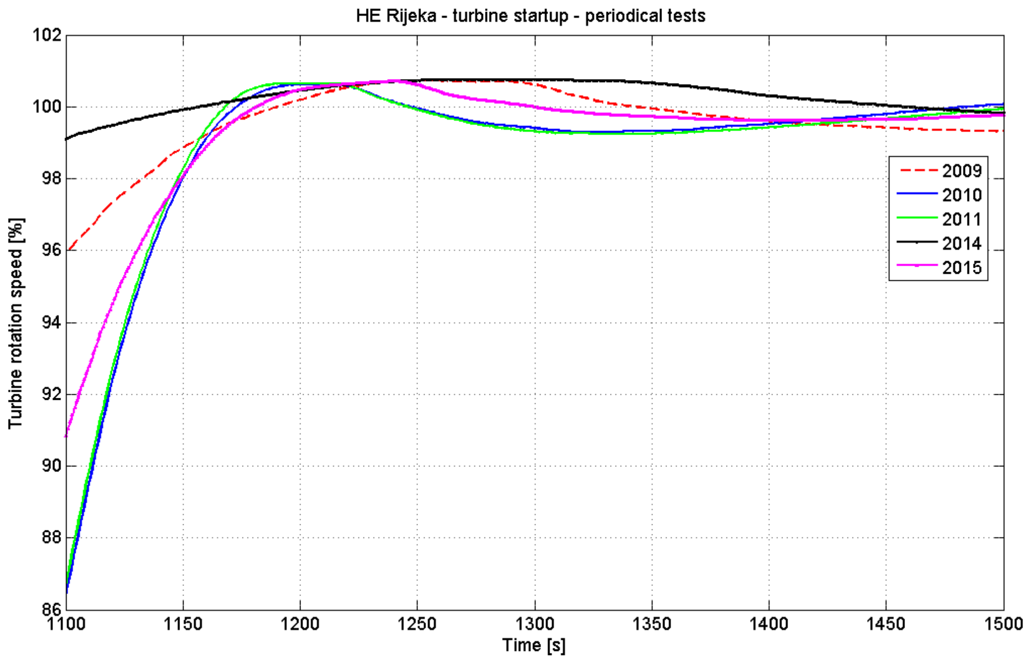

Figure 2: HPP Rijeka –turbine startup

Figure 2 shows pretty large variation in turbine startup behavior recorded in different tests. Similar behavior may be also seen in Figure 3 and Figure 4. The optimal curve shape should be defined by the project documentation.

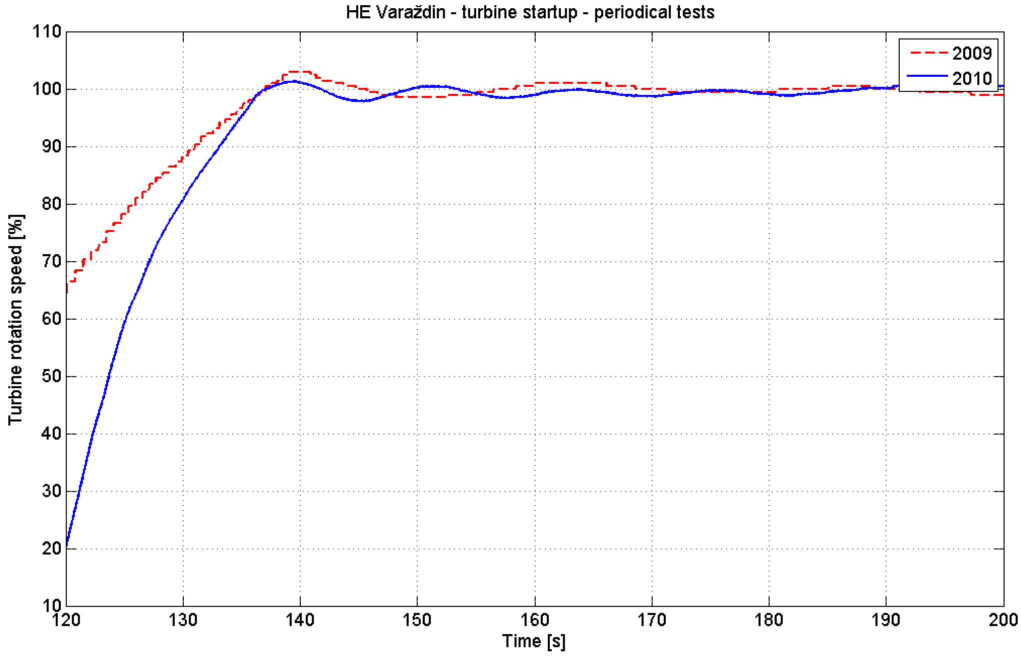

Figure 3: HPP Varaždin –turbine startup

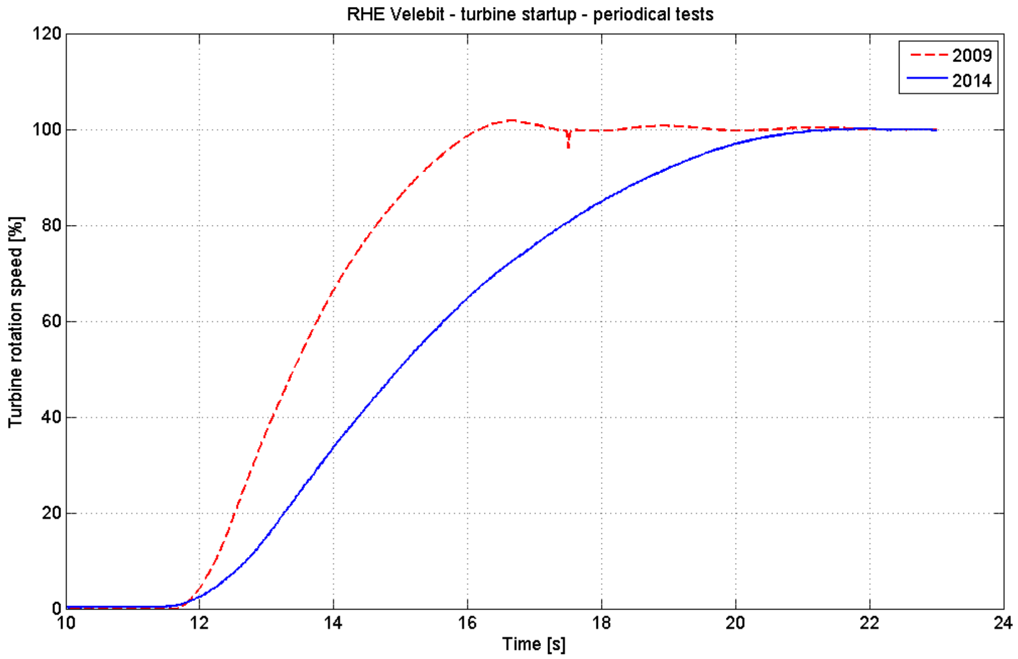

Figure 4: PSPP Velebit –turbine startup

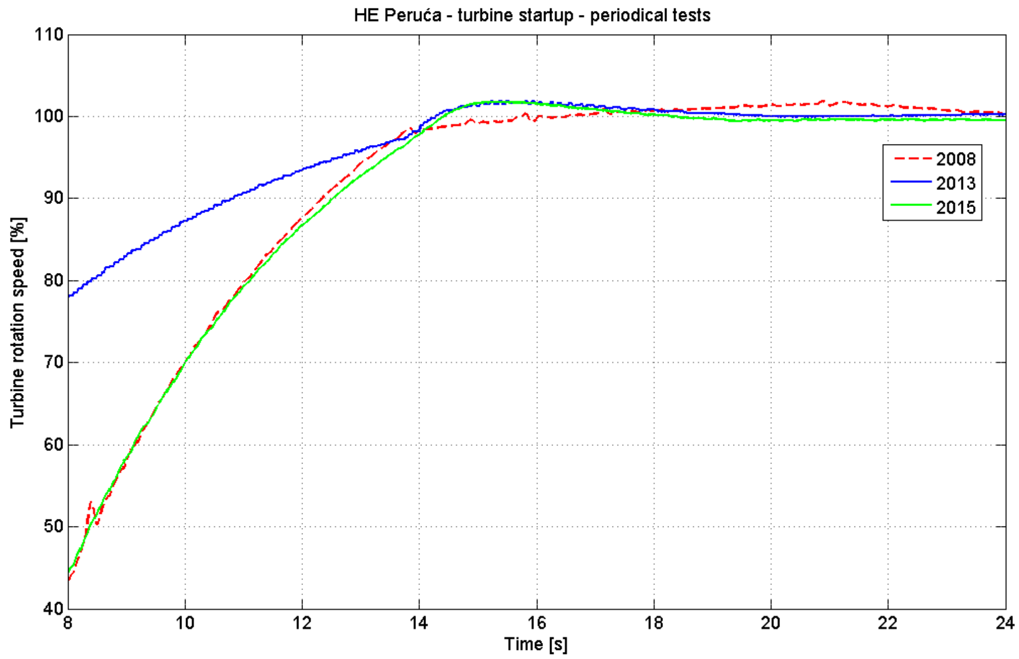

Figure 5: HPP Peruća –turbine startup

Figure 5 shows two startups (2008. and 2015.) from 0% to 100% and one startup (2013.) when the machine was not started from still mode.

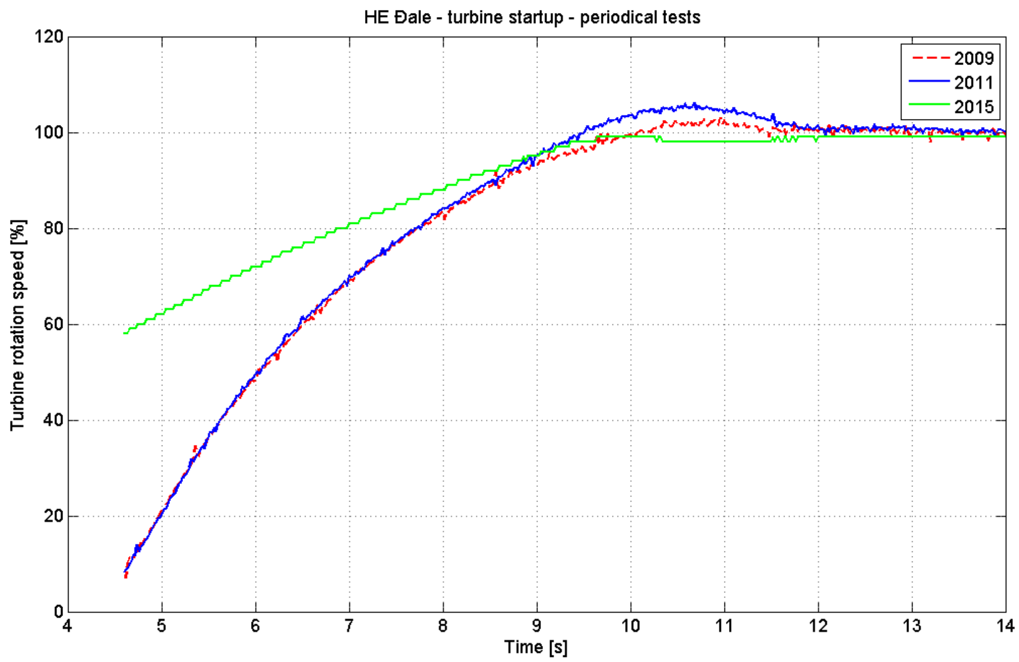

Figure 6: HPP Đale –turbine startup

The reason why the turbine from Figure 6 does have significantly different behavior in 2015. in comparison to two earlier tests is completely different regulator.

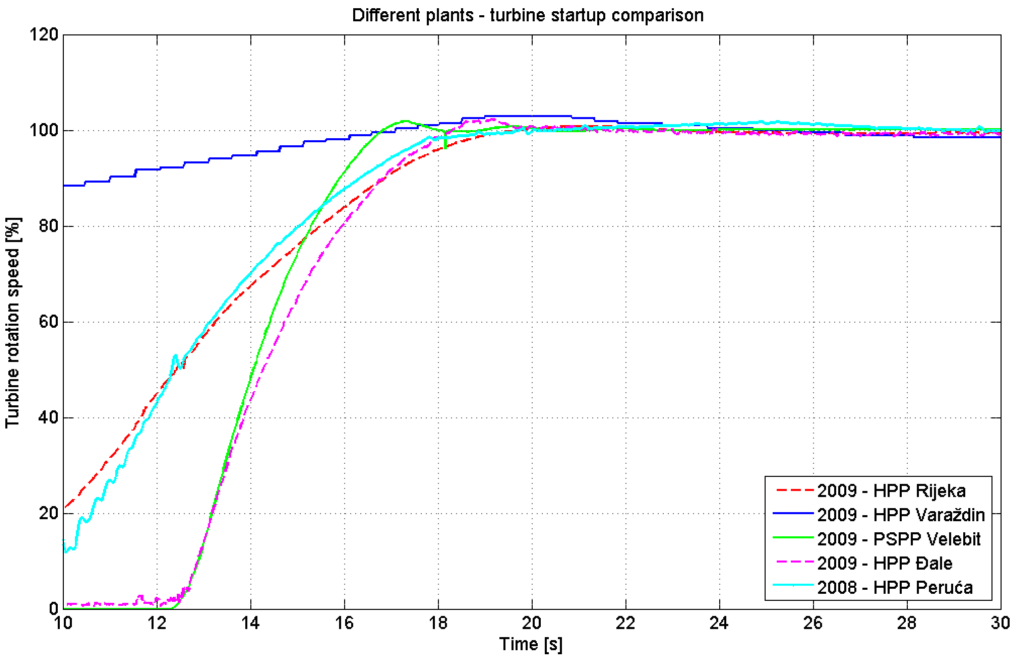

Figure 7: Turbine startup – comparison analysis

Figure 7 proves the fact that different systems have different behavior. It is also noticeable how HPP Varaždin has quite different, slow starting dynamics compared to other systems. HPP Peruća and HPP Rijeka have very similar but not identical startup curve shapes. They both have the Francis turbine, but the first system is part of an adjacent plant with a reservoir and the second one is installed in the run-of-river plant with a long penstock.

2.3 Power control

Power control is the most important segment of regulation. Due to the fact that the power output affects quality of the international power grid, many power control aspects are regulated by the law. The crucial parameters are variation of the referenced value (power and frequency), but also start-up time. The minimum speed of changing power is 1% of rated power in second. Primary regulation conditions are [2]:

- Static speed control system should be adjustable upon request of the transmission system in the range of 2% to 5%
- Insensitivity of the primary control is 20 mHz for new and refurbished generating units.

Secondary control has even more strict demands:

- Hydro generating units, intended for secondary control, must be capable of continuous change of active power from 1.5% to 2.5% Pn (Pn = nominal active power) between the minimum and nominal active power.
- The production unit must be able to provide the power grid, contracted reserve power for tertiary regulation no later than 5 minutes after application.

Additional requirement from the standard is:

- During the steady-state working regime, power output of the turbine shall not derivate from the reference value by more than 1.5% of rated output.

Comparison of different systems while changing power is given in Figure 8. Testing years are chosen randomly. Diversity of power curves in this figure originates from differences in system characteristics between various plants, as was the case in the speed control section. The desired power curves are set by plant design documentation in order to achieve optimum performance. They may differ between various plants, although all of them have to satisfy criteria set by the standards.

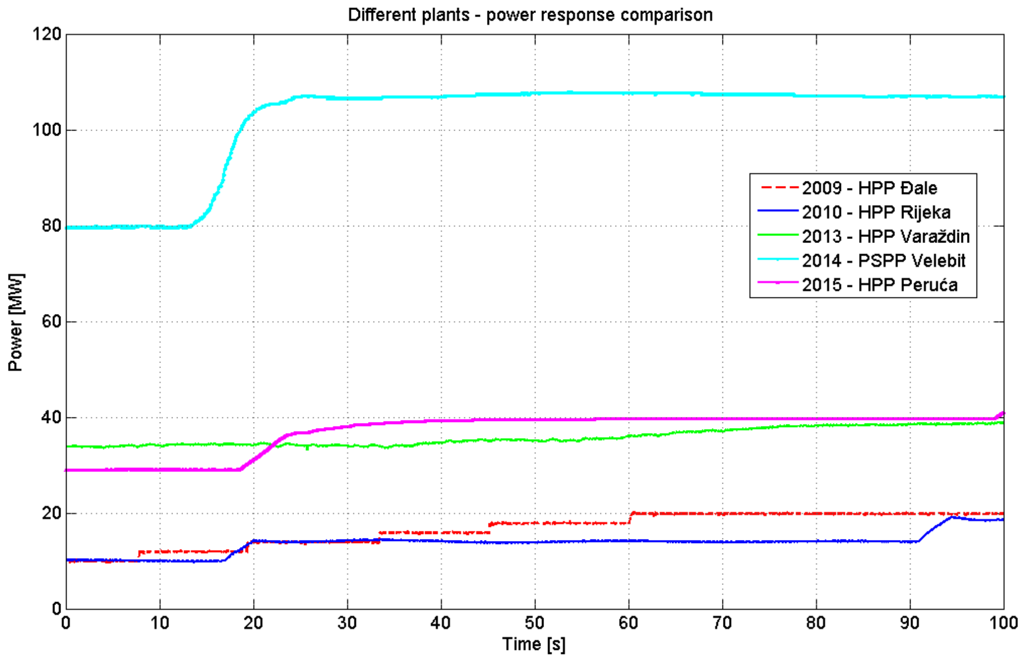

Figure 8: Power control – comparison analysis

3 Conclusion

The subject of presented tests was turbine system of hydro generating plants with different technical design. Results show small differences in system's behavior. It is yet to research if and how these tolerated deviations affect the system's health. Satisfying the standard is primary task, but with sophisticated measurements and adequate project documentation it is possible to set optimal configuration and extend lifetime of the system.

As already noted in the paper, testing turbine control system is done because of a few reasons: testing verifies the conformity with the technical regulations [3] and international standards [1] [2], detects possible defects, detects mistuning of parameters or parts, insensitivity and so on. This ensures that the power plant is more robust and meets the international standards, satisfying grid codes and reduces maintenance costs because the replacement of worn-out parts of the plant can be performed when the machine is not used in the production. New digital turbine systems allow performing required periodical tests much easier and faster. The annual plan of produced electric power is more reliable if positive result of such tests stands behind it.

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