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# Dynamic Electrical Simulation Model of NPP Krško

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## ABSTRACT

The paper presents an electrical simulation model of nuclear power plant Krško (NPPK). The model consists of a stationary and dynamic RMS (Root Mean Square) model of NPPK. The simulation models include the modelling of generator, steam turbine with the associated turbine governor, excitation system with the associated automatic voltage regulator (AVR), Power System Stabilizer (PSS), under-excitation, over-excitation and stator current limiters, generator step-up transformers, and supplementary consumption. The simulation model is parameterized based on technical documentation of the NPP building blocks and comparison of measured and simulated quantities. The simulation models are made in the DIgSILENT PowerFactory software.

## 1 INTRODUCTION

Republic of Slovenia is in a process of simultaneous green energy development and digitalization. A very reasonable step to facilitate and accelerate such transition, which is required by the EU Commission Regulations for System Operations [1] and Requirements for Generation units [2] as well as by the European Network of Transmission System Operators for Electricity (ENTSO-E) [3], is a creation of a simulation tool i.e., a specified digital twin of the real electric power system. In the digital environment such tool enables simulations of electromechanical transients in the electric power system and provides detailed observability of the power system dynamics and stability – a challenge which becomes even more important because of the implementation of the Renewable Energy Sources (RES) in parallel to the pillars of the power system stable operation i.e., the Nuclear Power Plants (NPP). In that respect a digital twin of the existing NPP Krško is proposed.

Dynamic modelling of the power network elements is an established way to emulate certain events that occur in the electrical power system, especially if it is hazardous to initiate such events in the real world to observe their outcome. Reliability is especially of the essence in the area of nuclear power, so it is even more important to provide a type of safe “sandbox” for the case of a nuclear power plant. In order to make a model of a power plant, correct models must be chosen or made and then their behaviour calibrated to what we can observe – measurement data of certain events. Any technical details that weigh upon the behaviour of the plant must be considered. Once the model sufficiently emulates the measurements, it can be considered accurate and further used as a “digital twin” of the actual power plant. Operation of NPPK greatly influences the operation of the Slovenian power system, so any stability studies involving said system can benefit from the model of the plant itself.

## 2 DESCRIPTION OF NEK POWER PLANT

Nuclear power plant (NPP) Krško (slo. Nuklearna Elektrarna Krško - NEK) is a 2$^{nd}$ generation[1] pressurized water reactor (PWR) plant with a nominal power of 727 MWe. It is connected to the high-voltage (HV) grid with two transformers (GT1 and GT2) as shown in the schematic in Figure 1. Transformers T1, T2 and T3 supply the house-load of the plant. The plant excitation system is normally set to maintain a constant 21 kV on the generator terminals, the voltage on the HV side is controlled with tap changers on both main transformers.

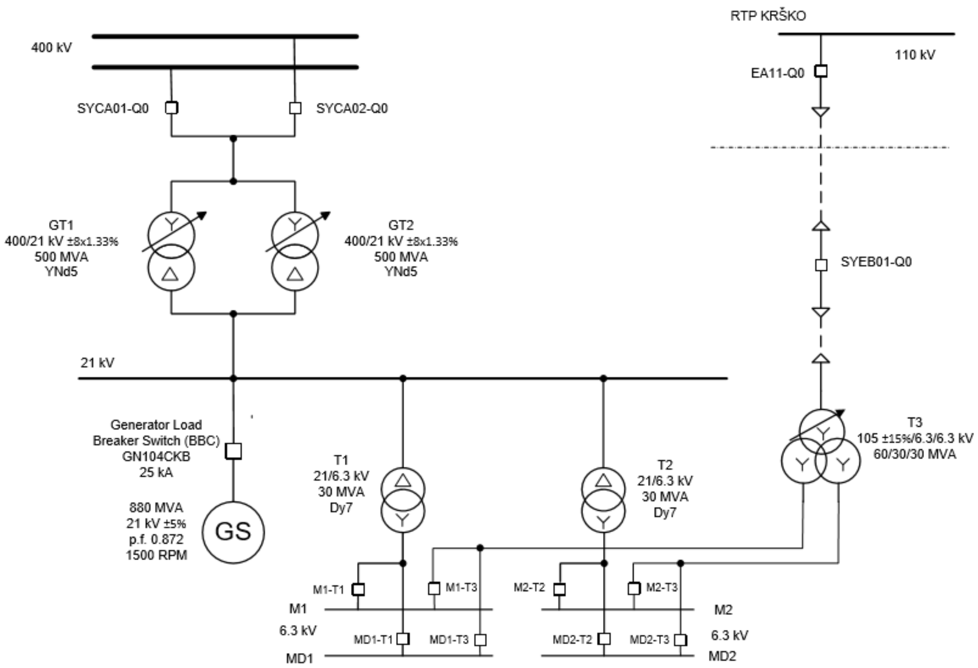


Figure 1: Scheme of NPPK connection to the grid

### 2.1 Turbine-governor system

About a third of the thermal power of the reactor (1994 MWt) is converted to mechanical power with turbines and then to electrical power with the generator. The general configuration of the turbine system in nuclear plants is shown in Figure 2. NPPK has a single high pressure (HP) turbine and two low pressure (LP) turbines on the same shaft. The flow of steam to the HP turbine is controlled with 4 governor/control valves (GV/CV). The fast-acting stop valve

[1] Due to the upgrades and operational improvements in the 40-year lifespan of NEK, this NPP can be considered as 3$^{rd}$ generation PWR.

(or main inlet stop valve MSV as in Figure 2) bypasses the flow of steam in case of power plant outage. The steam leaving the HP stage passes through a moisture-separator-reheater (MSR) which increases the efficiency of both LP stages. At the entry to the LP stages are the intercept valves (IV). The steam exits from the LP stages into the condenser. During normal operation, IV in NPPK have 2 positions – they are either completely open or closed, unlike GV. IV are spring-loaded, so they can close instantly and have a slow opening time (approximately 30 seconds).

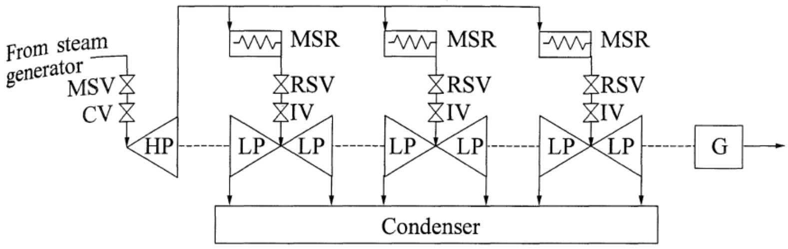


Figure 2: General turbine system configuration on a typical NPP (NPPK has only a single MSR and one pair of LP turbines) [4]

Governor systems in NPPK are operated by programmable digital electro-hydraulic system (PDEH). PDEH monitors parameters of the plant and can detect several operation scenarios, such as islanding. It then regulates valve positions accordingly. The governor has several modes of operation: speed control, automatic synchronization, and load control. The load control schematic is shown in Figure 3. The plant is in load control when it is connected to the grid and can then operate in constant power mode, power regulation mode or in pressure mode (power regulation in respect to available steam pressure). When the plant is connected to the grid, the frequency correction (FC) function is automatically enabled. FC acts to preserve the generator speed in set limits by adding or removing power to the turbine. It is set to react only after any frequency deviation persists for more than 2 seconds. The frequency deadband is ±200 mHz and frequency droop 8 %.

The switch from load to speed control is activated only when the generator or HV breaker are switched off. PDEH also includes a load-drop anticipation (LDA) function which is activated when the plant is operating above 30 % nominal power and the HV breakers are switched off. When the plant starts operating in its own island the IV and GV valves are closed, and the speed control is activated. GV start opening only when the turbine speed drops below nominal (3000 rpm). The GV are then governed by PID control to stabilize rotor speed. In case LDA trip, droop is disabled.

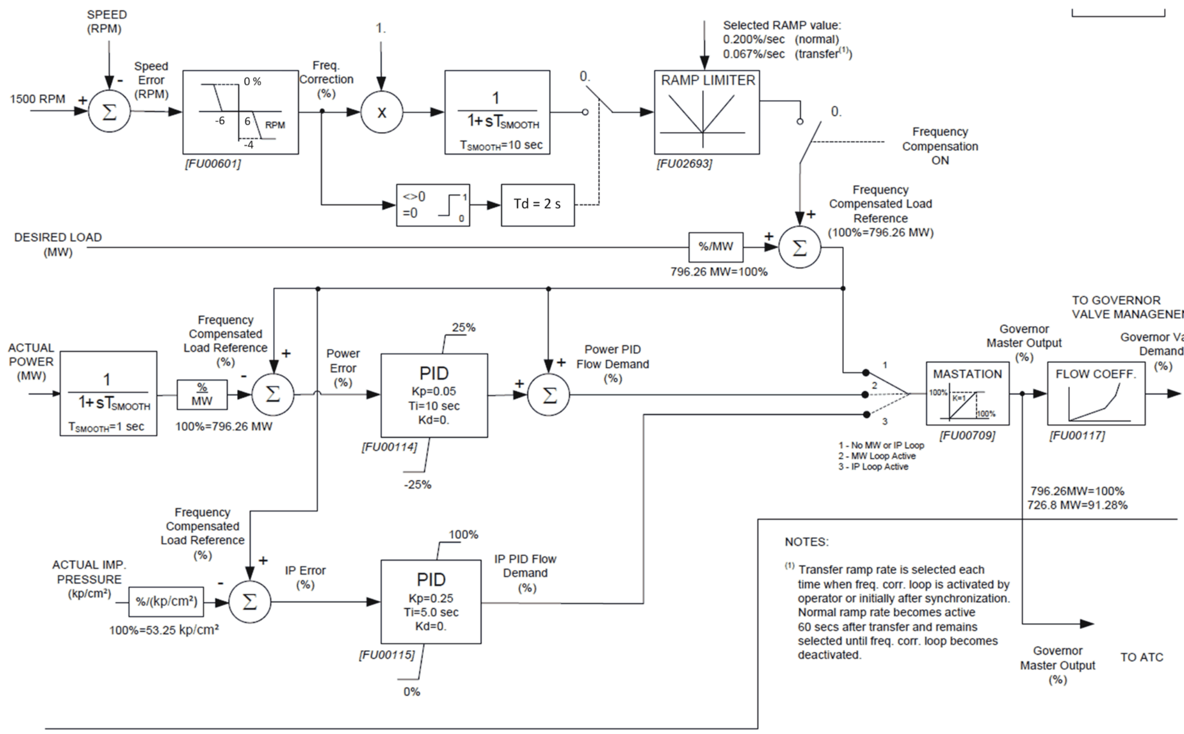


Figure 3: Governor load control schematic of PDEH system [5]

## 2.2 Excitation system

Figure 4 shows a general schematic of NPPK excitation system. The exciter rotates on the same shaft as the generator (with 6-pulse rotating diode rectifiers). The pilot exciter (synchronous generator with permanent magnets) provides an excitation field for the AC exciter. The DC field current from this exciter then feeds the field windings of the main generator. A regulator controls the pilot exciter filed current with thyristor converters. This consequently affects the size the AC exciter current and thus also the size of main generator field.

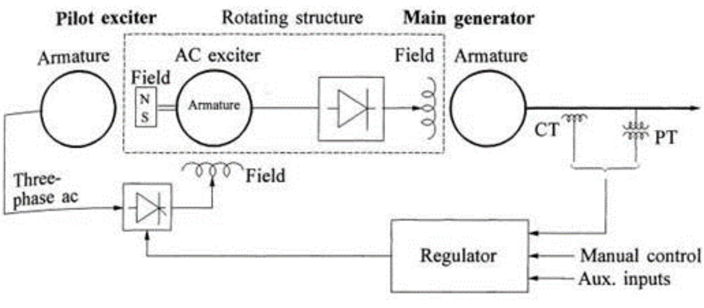


Figure 4: NPPK excitation system general schematic

## 2.3 House load

The house-load of the plant amounts to about 33 MW/14 Mvar. It is usually supplied through T1 and T2 transformers but can also be supplied either with T3 transformer connected to the 110 kV grid, with three diesel generators or with a HV line connection to the gas units in nearby Brestanica gas power plant. Motors represent most of the house-load consumption and are modelled with an equivalent (lumped) motor model in our analyses.

# 3 DYNAMIC MODEL OF NPP KRŠKO

Dynamic electrical model of NPPK is designed in DIgSILENT PowerFactory simulation program [6]. The dynamic model consists of the synchronous generator, an excitation system (with all the limiters and stabilizer included), the turbine-governor system as well as the network shown in Figure 1. Selection of the model parameters is either taken from the factory documentation of the equipment or performed by comparing the simulated dynamic response of the power plant with measured responses recorded during past events. Valid parameters are obtained once the discrepancy between the two responses is minimal.

## 3.1 Excitation system parametrisation

The IEEE AC7C model [7] is used to represent the response of the plant's rotating exciter. Models OEL5C, UEL1, SCL1C and PSS2B represent the overexcitation limiter, underexcitation limiter, stator current limiter and power system stabilizer, respectively. Parametrisation of the models is based on measurements of the plant's full-load rejection and subsequent transition to house load operation. Measured and simulated responses of voltage and reactive power on the generator's terminal side after the parametrisation are shown in Figure 5. After the load rejection the generator's reactive power changes from -60 MVAr to the house load consumption of 20 MVAr. This is accompanied by a voltage transient. The measurements have a sampling time of 1 second and thus the initial decrease and high slope increase of voltage, which is noticeable in the measurements, is not apparent. Also, the measured reactive power has a 2-second recording delay. Considering this we can conclude that the recorded and simulated responses of the excitation system are in good match.

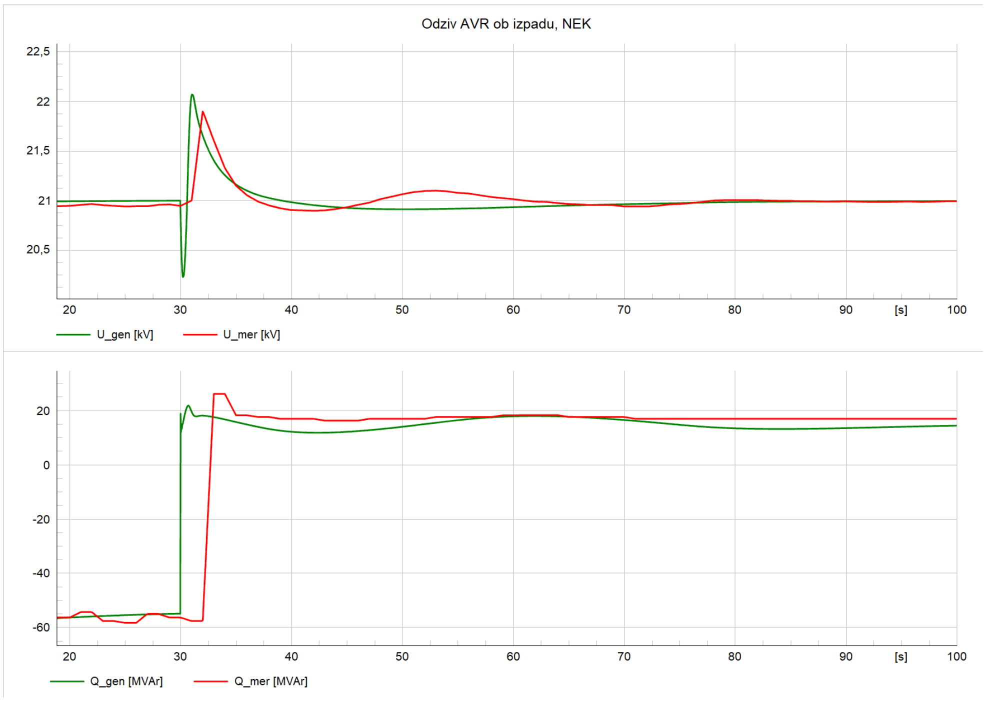

Figure 5: NPPK excitation system response (simulated = green, measured = red)

## 3.2 Turbine-governor system parametrisation

Any standardized (e.g., IEEE) models cannot effectively replicate the complex behaviour of the turbine-governor system in NPPK described in chapter 2.1. Therefore, a custom turbine-governor system was designed in PowerFactory and is shown in Figures 6 and 7.

The custom model fully replicates the behaviour of actual turbine-governor systems in NPPK with all the functionalities described in chapter 2.1. The nonlinear functions, such as those of fast-acting IV valves, are executed with custom coded blocks. It is made to initialize and normally operate in constant power mode. It can automatically enable FC and emulate the LDA function, as the state of main generator breaker is always being read by the governor model.

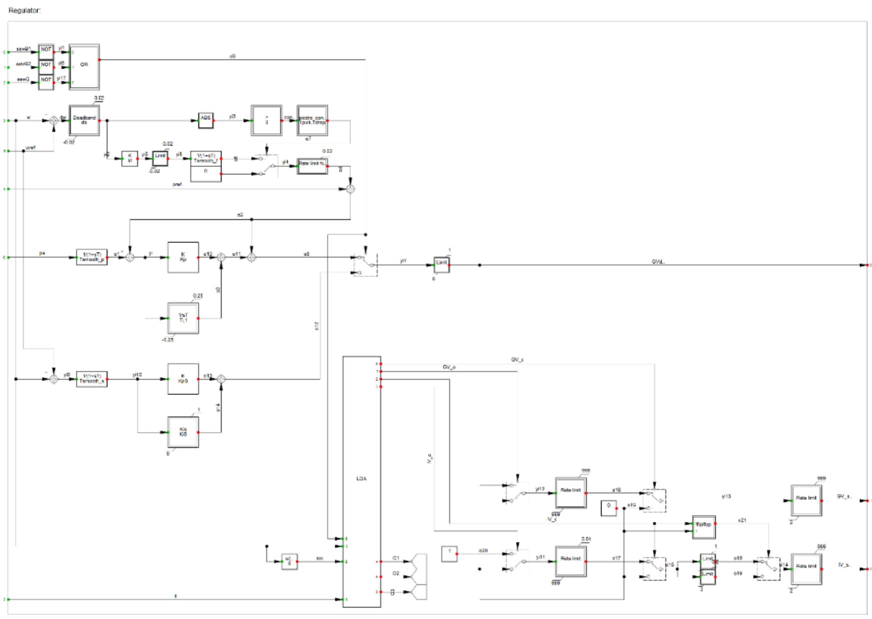


Figure 6: NPPK custom governor model in PowerFactory

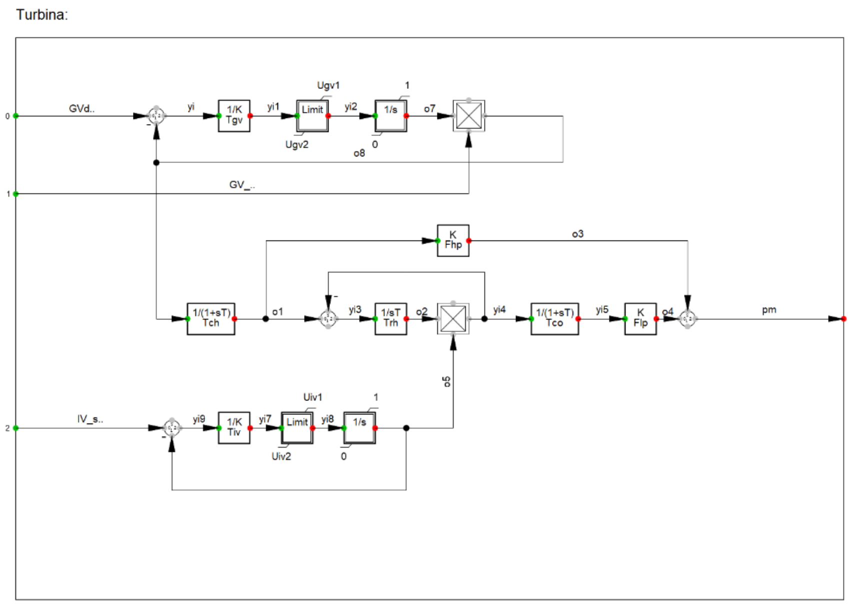


Figure 7: NPPK custom turbine-valve model in PowerFactory

An example of simulated and measured response of NPPK (frequency and active power) during full-load rejection event is shown in Figure 8. The operating power of the plant is suddenly decreased from about 700 MW to about 40 MW (house load power). As a result, frequency rises and starts dropping as soon as the fast valving takes effect. Speed control is activated, and frequency gradually (after about 100 seconds) stabilizes at the nominal value of 50 Hz. The discrepancy of measured and simulated frequency between 40 and 80 second marks in Figure 8 is not critical and is also fully expected as the model cannot fully replicate the valve position and steam pressure behaviour of the plant. This also has practically no effect on the external network.

Despite the latter, load rejections give a critical insight on how inertia and mechanical damping work in acceleration and slowing down of the rotor, so emulating them well is crucial to empirically estimating these values. Overall, the simulated frequency of the custom model is in good match with measured frequency. We can therefore conclude that the turbine-governor model can be used for simulating the behaviour of NPPK in the transmission network.

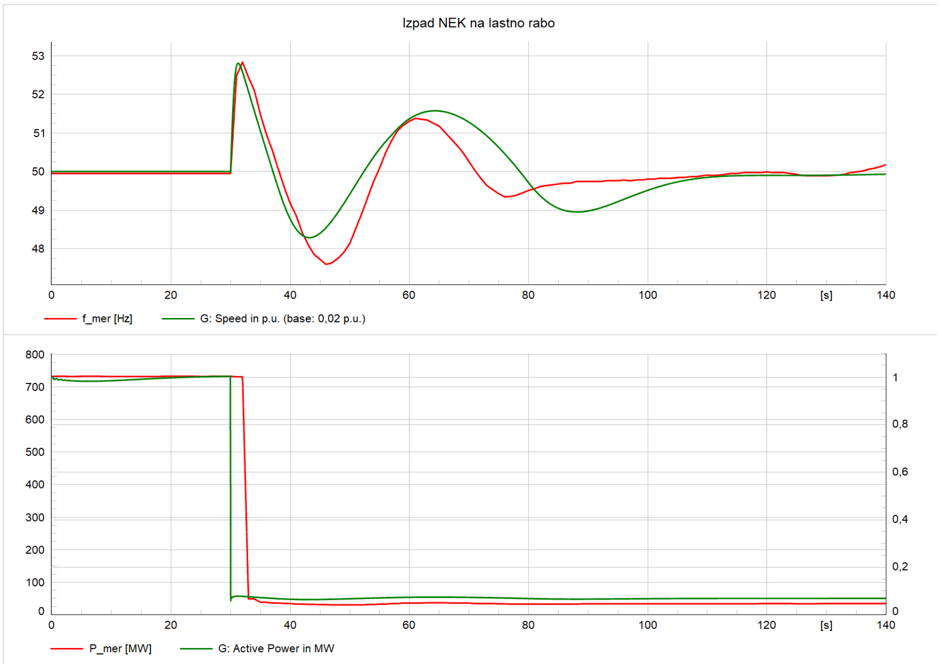

Figure 8: NPPK response at full rejection event (simulated = green, measured = red)

## 4 CONCLUSIONS

A dynamic model of the NPPK is presented in the paper. A standardized excitation system model and a custom turbine-governor model are used. Small discrepancies between measured and simulated models confirms the validity of both models which means that the dynamic model of NPPK can be used in stability studies which encompasses the whole transmission network of Slovenia.

The digital twin of the NPP Krško shows the importance in the wider power system operations. NPP Krško significantly contributes to the stability and reliability of the Slovenian electrical power system. NPP Krško crucially preserves the power system inertia and thus improve its electromechanical disturbance immunity and essentially enables the development of the unpredictable RES.

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