Simulation modelling for new gas turbine fuel controller creation.

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Abstract. State of the art gas turbine fuel flow control systems are based on throttle principle. Major disadvantage of such systems is that they require high pressure fuel intake. Different approach to fuel flow control is to use regulating compressor. And for this approach because of controller and gas turbine interaction a specific regulating compressor is required. Difficulties emerge as early as the requirement definition stage. To define requirements for new object, his properties must be known. Simulation modelling helps to overcome these difficulties. At the requirement definition stage the most simplified mathematical model is used. Mathematical models will get more complex and detailed as we advance in planned work. If future adjusting of regulating compressor physical model to work with virtual gas turbine and physical control system is planned.

1. Introduction
Technical-and-economic indices of combined cycle gas turbines (CCGT) are quite high. It is typical for modern energetics, including Russian energetics, to adopt gas turbine plants. Efficiency of the most advanced gas turbines is about 60%. Combustor is to accept high pressure fuel. Gaseous fuel distribution system pressure is often lower than needed. In such cases fuel gas compressor stations are built [1]. These fuel gas compressor stations significantly increase initial cost and power consumption. Considerable amount of attention is paid to perfection of combustor fuel gas delivery technology. New compressor machines are being developed [2], [3], [4], [5]. Besides compressor machines perfection, considerable amount of attention is paid to ways of combustor fuel gas delivery and compressor machine integration into gas turbine plant [6], [7], [8]. Major power consumption is due to compressing fuel gas to pressure much higher than in the combustor (because of pressure losses in fuel valves and heat-exchanging units). After compressor gas must be cooled down (fuel valves are designed to work with low temperatures), thus wasting energy. Fuel gas compression energy consumption can be decreased if fuel gas compression process and fuel gas flow control process are combined. Regulating compressor will feed fuel directly into combustor. Thus cooling and throttling system, which has the most pressure losses, can be removed.
2. Problem statement
Centrifugal flow compressors can be used as regulating compressor and flow control can be performed through rotation speed alteration. Centrifugal compressor has many advantages, one of them is acceptable weight-and-dimensional values and low response time. And as all impeller machines, it has instability zone. When designing regulating compressor requirements must be stated so that it is stable at all times. With modern computational tools it is possible to simulate any working conditions of regulating compressor. Same tools can be used in further refinement work on following development stages. The goal was set to design a research device that will be capable of determination of possible regulating compressor and gas turbine cooperation zones, determination of dynamic response of gas turbine plant with regulating compressor, troubleshooting and adjusting regulating compressor and control system.

3. Essential concepts of simulation environment building.
At the first step simulation environment is represented by set of virtual objects that are based on very simplified mathematical models. Fig. 1 shows schematic diagram of simulation environment.

![Schematic diagram of simulation environment.](image)

Simulation environment consists of six simulation model units (surrounding environment unit, gas distribution unit, power consumer unit, gas turbine plant unit, fuel gas compressor unit, control system unit).

3.1. Mathematical definition of surrounding environment.

Surrounding environment model is static model that receives information (surrounding environment temperature and pressure) from console. Information from console is converted into analog signal and then back to digital (needed for quick measurement device switching without model reprogramming). It was assumed that air composition does not change (and humidity does not change too); it was assumed that surrounding environment feedback is negligible.

3.2. Mathematical definition of gas distribution system.

It was assumed that gas distribution system feedback consists only of influence of gas flow rate on gas distribution system pressure. It is also assumed that fuel being ideal gas, i.e. gas composition is not considered. Given input parameters vector will comprise of heat capacity, pressure and temperature at the gas distribution system outlet. Resulting output parameters, such as average pressurizing process heat capacity and gas distribution system outlet temperature and pressure, are relayed in form of numbers to fuel gas compressor model where they are converted to analog signals.

3.3. Mathematical definition of power consumer.
Power consumer model simulates different power consumer conditions and information about influence of consumer on gas turbine plant is defined as function of power generated by gas turbine plant, which power is directed to control systems. Also control system receives various instructions from network supervisor or operator that have influence over consumer.

### 3.4. Mathematical definition of gas turbine plant.

There are many works dedicated to gas turbine plant model creation [9], [10], [11], [12]. Essential equation system remains same. Differences are mainly consist of tasks, mathematical model detailisation degree and methods of equation system solving. In this case gas turbine plant model is detailed up to node. Node is considered as gas turbine plant component such as air filter inlet unit, compressor, combustor, turbine, exhaust unit and generator. Each node is defined as simplified approximated function.

### 3.5. Mathematical definition of fuel gas compressor

Model of fuel gas compressor, as well as gas turbine plant model, is detailed up to major nodes (converter, motor-generator and compressor). At the first step simplified node models are used. Considering that model in question is meant for fuel gas compressor development support, models will be adjusted and elaborated further in time. At the stage of fuel gas compressor physical model construction, this physical model will replace virtual one and will be adjusted to work with virtual gas turbine plant model. After finishing, a releasing tests of prototype gas fuel compressors are planned to be performed in described simulation environment.

### 3.6. Simulation model of control system.

At the first step control system model will be simplified. It mostly will generate control signal for gas fuel compressor converter. Besides it will measure virtual parameters generated in simulation environment units. At the stage of fuel gas compressor physical model finishing usage of real gas turbine plant control system is expected. Finishing touches will be applied both to control system and to fuel gas compressor.

### 4. Hardware and software.

Fig. 2 shows National Instruments CompactRIO 9036 that was used as the main hardware tool. It comprises of 8 RS-232 slots, ADC, DAC, real-time processor and field-programmable gate array (FPGA).

[Fig. 2. CompactRIO cRIO-9036.]

Controller operated under LabVIEW Real-Time Module and LabVIEW integrated development environment (IDE), which uses G scripting language, was used. Program execution is defined by instruction sequence, using stream programming. Another advantage of this IDE is that it can compile written programs.
5. Simulation environment usage on example of static condition research of fuel gas compressor with single-shaft gas turbine plant.

Operation of developed simulation environment was tested on two cases. In the first case, steady-state conditions cooperative work of gas fuel compressor and single-shaft gas turbine plant was evaluated. Table 1 shows general parameters of single-shaft gas turbine plant.

| Parameter                                           | Value  |
|-----------------------------------------------------|--------|
| Nominal rating power, MW                             | 1.8    |
| Peak output at low air temperatures, MW              | 2.2    |
| Gas temperature before turbine at nominal rating power, K | 1250   |
| Gas temperature after turbine, K                     | 830    |
| Working medium flow rate, kg/s                       | 8.7    |
| Compression ratio                                    | 6.7    |
| Fuel gas flow rate, kg/hr                            | 490    |
| Fuel gas compressor inlet pressure, MPa              | 0.4    |

![Fig. 3: Working conditions of gas fuel compressor. a) Instability edge, b) working conditions at -55°C, c) working conditions at +15°C, d) working conditions at +45°C.](image)

Fig. 3 shows fuel gas compressor performance curve with working condition lines at different air inlet temperatures and single-shaft turbine. Should be noted that working condition lines of single-shaft gas turbine plant are considerably far away from each other. When selecting reference point for gas fuel compressor must be considered that working condition line is located almost 15% closer to instability edge at negative temperatures than at normal air temperature of 288K.

6. Simulation environment usage on example of static condition research of fuel gas compressor with gas turbine plant and free power turbine.

As the second example steady-state cooperation work of gas fuel compressor and gas turbine plant was evaluated. Table 2 shows general parameters of single-shaft gas turbine plant.
| Parameter                                                                 | Value |
|---------------------------------------------------------------------------|-------|
| Nominal rating power, MW                                                  | 2.5   |
| Peak output at low air temperatures, MW                                   | 3.0   |
| Gas temperature before turbine at nominal rating power, K                 | 970   |
| Gas temperature after turbine, K                                          | 660   |
| Working medium flow rate, kg/s                                            | 25.7  |
| Compression ratio                                                         | 6.7   |
| Fuel gas flow rate, kg/hr                                                 | 890   |
| Fuel gas compressor inlet pressure, MPa                                   | 0.4   |

Fig. 4: Working conditions of gas fuel compressor. a) Instability edge, b) working conditions at -55°C, c) working conditions at +15°C, d) working conditions at +45°C

Fig. 4 shows fuel gas compressor performance curve with working condition lines at different air inlet temperatures and free power turbine. Temperature splitting is mostly negligible when working at steady-state conditions with free power turbine. Working zone is stretched almost in a line and this line is located quite far from instability zone edge. Researches show that working zone is heavily influenced by gas turbine plant kinematic configuration. In case of free power turbine it is easily solved. In the case of single-shaft power turbine, special approach to fuel gas compressor is required to provide stable working conditions. Next step will be evaluating operation of fuel gas compressor at transient conditions and at the startup of gas turbine power plant.

7. Conclusion

7.1. Simulation environment was developed for research of working conditions of new type of fuel flow rate controller: fuel gas compressor.

7.2. Operation of developed simulation environment was tested on two cases. Steady-state working conditions of fuel gas compressor with gas turbine plant were evaluated. In the first case single-shaft power turbine was used and in the second case free power turbine was used. Results show that fuel gas compressor working conditions are heavily influenced by gas turbine plant kinematic configuration. In case of single-shaft power turbine the most dangerous conditions in scope of fuel gas compressor stability are of those when air inlet temperature is very low. In case of free power turbine all working conditions are located in safe zone. In any case it is required to evaluate fuel gas compressor operation at transient conditions and at startup of gas turbine power plant.
7.3. Future directions of simulation environment development are connected with improving of
detailization and accuracy of mathematical models that being used, replacing simulation models with
physical models or prototypes and conducting research and release tests of fuel gas compressor.

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