10.2478/v10144-009-0005-3

Simulation of gas-turbine driven device

Kristīna Bērziņa, Elena Ketnere
Riga Technical University (Riga, Latvia)
berzina@rtu.eef.lv, ketnere@rtu.eef.lv

***Abstract-* Power systems are combinations of electrical circuits and electromechanical devices. Engineers working in this discipline are improving the performance of the systems. This is one of the reasons, why the modeling of the power systems is required.**

I. INTRODUCTION

The development of the modern technologies increase human dependence on power supply in all areas: both in the household, and industry, and recreation sector. Human's direct dependence on continuity of power supply grows also for transport systems and in the medicine.

General distribution of computers only raises requirements to power supply. Not only quantity, but also quality of the electric power becomes very significant for banks, and telecommunication and industrial companies. Power cut in our days can lead not only to a stop or fault of the machine, but also to information losses restoration of which sometimes is comparably more difficult than the repair of the equipment itself.

The traditional way of power and heat generation consists of their separate generation (power station and boiler-house). Thus significant part of primary fuel's energy is not used. It is possible to considerably reduce the common consumption of primary fuel by cogeneration application. Cogeneration is a combined manufacture of electric (or mechanical) and thermal energy from the same primary energy source.

Two mostly used forms of energy are mechanical and thermal. Mechanical energy is usually used for rotation of the electrical generator. Produced mechanical energy also can be used to maintain the work of auxiliaries, such as compressors and pumps. The thermal energy can be used both for heating, and for cooling. The cold is made by absorb module which can function due to hot water, a steam or to hot gases.

II. THE COGENERATION SYSTEM

At operation of traditional thermal power station a plenty of produced heat is dumped to the atmosphere. The biggest part of this heat can be utilized and used for satisfaction thermal needs satisfaction, which raises efficiency from 30-58 % for power station up to 80-90 % in cogeneration systems (Fig.1.). Comparison between cogeneration and separate manufacture of electricity and heat is resulted in the Table 1 based on typical values of efficiency.

TABLE I
THE RESULTS OF COMPARISON BETWEEN COGENERATION AND SEPARATE MANUFACTURE OF ELECTRICITY AND HEAT.

Electricity and heat separated production	
Fuel 100 → Powerplant → Electricity 36 Fuel 100 → Boilerhouse → Heat 80	Efficiency 58%
Cogeneration System	
Fuel 100 → Cogeneration System → Electricity 35, Heat 55	Efficiency 90%

Application of gas plunger modular allows creating reliable independent system of power-heat-cold-supply at the enterprise. Besides, energy cost is 3-4 times lower than at purchase at the power companies.

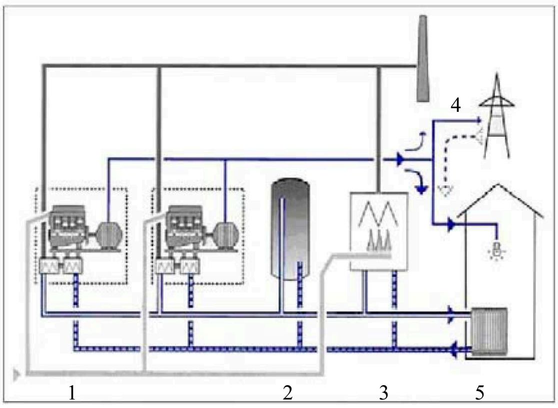

Fig. 1. A function chart of power station (PS) with modules of CGS (Cogeneration system). 1. Natural gas; 2. Boiler of network water; 3. Peak boiler; 4. Network; 5. Consumer

Requirements for power supply are formulated simply - reliability.

The use of cogeneration system's ensures that the consumer is prevented from faults in the centralized power supply.

Consumer, most likely, will not have organizational, financial or technical difficulties at growth of power of the enterprise, because of new buses, transformer substations and heating pipes are not required. Besides, newly gained cogenerations are built in already existing system.

The distributed (independent) energy sources such as cogeneration systems reduce vulnerability of a power infrastructure.

Cogeneration increases reliability of power supply. This is an essential advantage in conditions of the varying market.

Cogeneration provides a huge benefit in power efficiency. About 67 % of primary fuel's energy, using a traditional way of electric power generation, is thrown out in an environment (Fig.2.). Also additional losses exist, occurring by transfer of the electric power. Utilized heat can be used in technological processes: for manufacture of a cold (triplegeneration), for heating and air-conditioning of rooms, for water heating, etc. Reconstruction of existing boiler-houses with application of cogeneration units allows receiving the same quality for smaller price.

There are a lot of programs which uses the heat cogeneration installations in the world, for example TAT (Thermally Activated Technologies). TAT consider that: to the year 2020 5% of total energy consumed in the USA will fall to utilized thermal energy. The American industry demands acceleration the development of TAT for receiving of competitive advantages in economy and power in the future.

TAT are critical for maintenance of ecological safety and reduction of air pollution. The USA industry demands acceleration of air drainage and ventilation technologies development to make personal healthier and preservation of the environment.

Recycling of heat reduces an ecological load of any power equipment approximately two times.

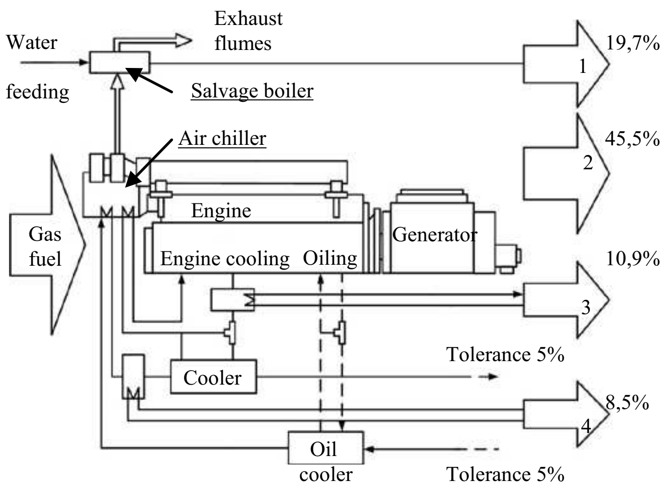

Fig. 2. The structure of the cogeneration device. 1. Steam – 19.7%; 2. Electric power – 45.5%; 3. Hot water – 10.9%; 4. Warm water – 8.5%.

III. THE SYNCHRONIZATION OF COGENERATION DEVICE

Cogeneration system's connecting in parallel work with the network is the complex and responsible operation demanding knowledge and strict observance of certain conditions.

Consequence of wrong inclusion of the generator in the network can be loss of current supply in trunks of power station, and under known conditions - damage of the switching equipment and the generator itself. Therefore big attention is paid to the synchronization of generators, both at designing, and at operation.

Synchronization methods that can be applied on independent cogeneration stations at generator's connecting in parallel work are:

– Exact synchronization. Before the generator connected to the electric system trunks, its voltage and frequency are established equal to a voltage and frequency of a network; at the moment when phases of both the network and the generator voltage coincide the generator is connected to the network;
– Self-synchronization. Before the generator connected to the electric system trunks its excitation winding is closed on digit resistance; the rotation frequency of the generator is established approximately equal to network's frequency. Then without consideration of network's and generator's voltage phase sequence, the generator is connected to the network with the subsequent excitation;
– Synchronization through resistance. The generator with voltage and the frequency approximately equal to network's voltage and frequency is connected to the network without consideration of network's and generator's voltage phase sequence [1].

These methods have the advantages and disadvantages and consequently application of this or that method depends on assignment of power station, generators' power, requirements to stability of network's voltage and frequency, etc.

To check the stability of any synchronization method it is necessary to determine first of all allowable angular speed of rotor sliding at the connected machine, and at exact or rough synchronization with restriction of an angle of switch-on and a limiting angle of switch-on. To estimate the value of the currents proceeding in system during synchronization, it is necessary to find an angle on which the generator deviates at switch-on, and also to analyze influence of superfluous moment changes, rotation frequency and excitation on synchronization process [2].

IV. THE MATHEMATICAL MODEL OF COGENERATION DEVICE

For an estimation of synchronization stability the mathematical model is developed. The model includes full differential Park - Gorev's equations for synchronous generator model and the primary engines differential equations.

All equations are written in relative unit's system "system Xad" or "per unit system", and both the mutual induction reactance's and magneto motive forces are equal among themselves. The gas engine's mathematical model is similar to turbo generator mathematical model.

The synchronous generator's mathematical model in d, q, 0 axes is following [5].

$$\left.\begin{aligned} u_0 &= \frac{d\Psi_0}{d\tau} + i_0 r; \\ u_d &= \frac{d\Psi_d}{d\tau} - \Psi_q\,\omega + i_d\,r; \\ u_q &= \frac{d\Psi_q}{d\tau} + \Psi_d\omega + i_q\,r; \\ u_f &= \frac{d\Psi_f}{d\tau} + i_f\,r_f; \\ 0 &= \frac{d\Psi_D}{d\tau} + i_D\,r_D; \\ 0 &= \frac{d\Psi_Q}{d\tau} + i_Q\,r_Q. \end{aligned}\right\} \quad (1)$$

Where Ψ_d, Ψ_q – are components of full flux linkages;

u_d, u_q, – are components of instantaneous values of phase voltages;

i_d, i_q, – are components of instantaneous values of phase currents;

r_d, r_q, – are active resistances of phase windings (in case of stator symmetry $r_d = r_q = r$);

u_f, i_f, r_f, Ψ_f – are components of voltage, current, full flux linkage, and active resistance of excitation winding;

$$\left.\begin{aligned} \Psi_0 &= x_0 i_0; \\ \Psi_d &= x_d i_d + x_{ad} i_f + x_{ad} i_D; \\ \Psi_q &= x_q i_q + x_{aq} i_Q; \\ \Psi_f &= x_{ad} i_d + x_f i_f + x_{ad} i_D; \\ \Psi_D &= x_{ad} i_d + x_{ad} i_f + x_D i_D; \\ \Psi_Q &= x_{aq} i_q + x_Q i_Q. \end{aligned}\right\} \quad (2)$$

If there is a surplus or lack of energy in system "gas engine - generator" the established mode is broken. Thus all change in time or only those parameters which define an overall performance of a gas engine. Thus the gas engine - generator shaft receives positive or negative acceleration, and the system passes to work in the unsteady (transitive) mode. If the resulted inertia moment J of a gas engine and the synchronous generator the dynamic balance condition describing an unsteady operating mode of a gas engine, can be written down according to Dalamber's principle:

$$J\frac{d\omega}{dt} = M_{dz} + M_{em} \quad (3)$$

Where M_{dz} - equality of the moment;
M_{em} -the generator's moment;

In relative units this equation will look like:

$$T_M\frac{d\omega}{dt} = M_{dz} + M_{em} \quad (4)$$

There are various gas engine various types: not direct and direct action, with turbo – supercharding and without it, thus considering a question of prevalence of those or other types of gas engines and comparing with their mathematical models, the direct action gas engine of with turbo – supercharding as initial model is accepted in this work. The differential equations' system describing behavior of a rotation frequency regulator of a gas engine, in Coshie form looks like:

$$\begin{aligned} \frac{d\mu_p}{d\tau} &= k; \\ \frac{dk}{d\tau} &= -\frac{1}{T_2''}\left[T_K k + \delta\mu_p + \delta i\left(\mu_p - \xi\right) + \left(\omega - \omega_0\right)\right]; \\ \frac{d\xi}{d\tau} &= \frac{1}{T_i}\left(\mu_p - \xi\right). \end{aligned} \quad (5)$$

Where T''_2 – a time constant of a sensitive element of a rotation frequency regulator;

T_k – a viscous friction time constant of a rotation frequency regulator;

T_i – a dash-pot time constant of a rotation frequency regulator;

μ_p – moving of regulating body of a rotation frequency regulator;

δ – constant-error response of a rotation frequency regulator;

δ_i –temporary (additional) constant-error response of a rotation frequency regulator;

ξ – a dash-pot moving of a rotation frequency regulator;

ω_0 – a rotation frequency regulator setting;

ω – a rotation frequency of the synchronous generator with a drive from the internal combustion engine (gaze engine) [3].

The turbo-supercharging turbine's impact on dynamic properties of a gas engine is advantageous, but only for the chosen operating mode. At change of optimum conditions setting accordingly elements characteristics of gas engine or turbo-compressor are broken and teamwork's quality declines.

The turbine's impact on gas engine's work is taken into account by equation

$$\frac{d\omega_T}{dt} = \frac{1}{T_T}\left(\mu_p - \omega_T\right) \quad (6)$$

Where T_T - a turbine time constant;

ω_T - The turbo-supercharging turbine rotation speed.

Finally a gas engine mathematical model is:

$$\begin{aligned} \frac{d\mu_p}{dt} &= -\frac{1}{T_k}\left[\delta\cdot\mu_p + \delta_i\left(\mu_p - \xi\right) + \left(\omega - \omega_0\right)\right]; \\ \frac{d\xi}{dt} &= \frac{1}{T_i}\left(\mu_p - \xi\right); \\ \frac{d\omega_T}{dt} &= \frac{1}{T_T}\left(\mu_p - \omega_T\right). \end{aligned} \quad (7)$$

It is necessary to have the voltage equilibrium equations of electric contours both on stator and rotor, and the rotor's movement equation in the differential form for the research of rotating electric machines transient processes, particularly in synchronous generators [4]. The kind of these equations depends on a choice of coordinate axes positive directions and a direction of a current in contours.

To show simulation of the generator model with a gas engine the analysis of a synchronization regime with an infinite power network is performed.

Gas turbines have regulation units that allow doing the following functions: control of the fuel flow, adaptation of the electrical signals for their use in the conventional electric network, voltage and frequency regulation.

In this simulation, a one phase fault is generated at the output terminal of the gas turbine at t = 5 s.

Simulation has been performed in order to study the response of the grid connected gas turbine to a variation in the power set-point.

Figures 3 – 5 show results of the cogeneration system connecting to the network with breaking synchronization conditions. The beginning initial is same in all cases. It was analyzed thermal energy quantity (BTU), current, and voltage fluctuations per seconds are analyzed [6].

In North America, the term "BTU" is used to describe the heat value (energy content) of fuels, and also to describe the power of heating and cooling systems, such as furnaces, stoves, barbecue grills, and air conditioners. When used as a unit of power, BTU 'per hour' (BTU/h) is understood, though this is often confusingly abbreviated to just "BTU".

The British thermal unit (BTU or Btu) is a unit of energy used in the power, steam generation, heating and air conditioning industries. In scientific contexts the BTU has largely been replaced by the SI unit of energy, the joule (J), 1 kJ = 1,055 Btu. For description the cogeneration system's power, at this paper, was used BTU.

Figure 3 shows the one phase current at gas turbine terminals.

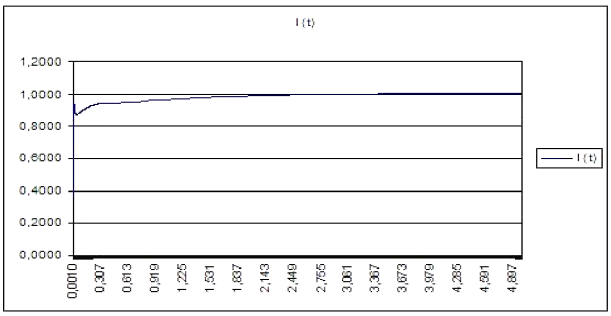

Fig. 3. One phase current at gas turbine terminals vs time

Figure 4 show the one phase voltage at gas turbine terminals.

Figure 5 show the one phase British thermal unit at gas turbine terminals.

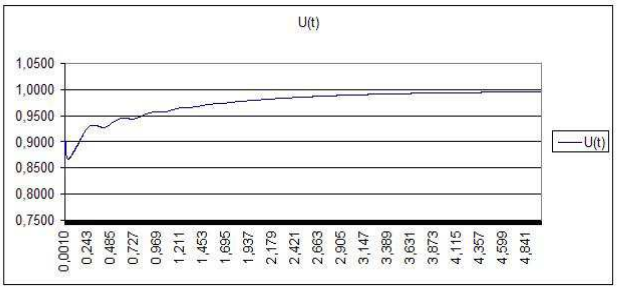

Fig. 4. One phase voltage at gas turbine terminals vs time

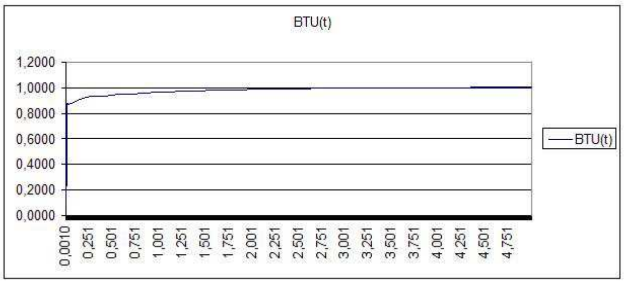

Fig. 5. One phase Btu at gas turbine terminals vs time

CONCLUSIONS

On the mathematical model's basis there is possible with high degree of reliability to define synchronization conditions of generator with a drive from the internal combustion engine. To determine possible deviation limits on rotation frequency and mismatch corner of exact synchronization. Results of the cogeneration system connecting to the network with breaking synchronization conditions make sure, that system work orderly, and synchronization was successful. Also the offered program allows estimating a value of stator currents and electromagnetic moment of synchronous generator.

With help of this model it's possible to simulate regimes, which would cause enormous economical loses in real operation. By analyzing this kind of disturbances, engineers could find solutions for them and minimize the risks and consequences of them. Also it's possible to tune the parameters of control units and raise the effective of the power system.

REFERENCES

[1] И. П. Копылов „Электрические машины," М.: Высшая школа; Логос; 2002.

[2] Горев А. А. Переходные процессы синхронной машины. М.: Госэнергоиздат; 1950.

[3] K. H. Park "Two reactions theory of synchronous machines," Generalized method analysis/ PtI, Trans. AIEE, 1929.

[4] Л. Н. Токарев „Математическое описание, расчет и моделирование физических процессов в судовых электростанциях," Л.: Судостроение,1980.

[5] Dirba J., Ketnere E., Ketners K. Synhronization (resynhronization) modes: modelling and simulation. Latvian Journal of physics and technical sciences, Riga, 1999.

[6] R. Šeļegovskis Metodiskie norādījumi praktiskajiem darbiem LLU TF Lauksaimniecības enerģētikas specialitātei studiju kursā, Siltumzinību pamati, Jelgava, 2006.