The Steam Pressure Impacts Reducing System for a Biomass Cogenerator Based on Monitoring of the Frequency Characteristics of the Steam Actuator

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Abstract

Introduced through policy instruments, as well as due to increase awareness of and demand for energy, alternative, renewable energy sources are becoming increasingly popular and necessary. The growing market and standards are forcing producers of renewable energy sources to constantly improve the quality of their products. Biomass trigenerators are one way of obtaining such energy, both in the form of electricity, heat and cold. These are elements generating steam by burning various solid, liquid or gaseous fuels of organic origin. Rotating machines in the form of turbines or steam engines are used to generate electricity. Unfortunately, they are particularly exposed to steam impacts associated with discontinuous work. This article presents the monitoring and prevention system for such impacts. It is based on the analysis of the frequency spectrum of vibrations of such generators and can be used to implement a trigenerator control system that will reduce the influence of such impacts. With proposed diagnostic system, the efficiency and life span of a Renewable Energy Source can increase significantly

Keywords: steam generator, fault diagnosis, vibration response, biomass, water hammer

1. Introduction

According to the new emission reduction requirements, conventional energy systems will be replaced by technologies that do not require fossil fuels. Solutions are sought that will allow heat, energy, chill to be generated irrespective of atmospheric conditions, diversify source of heat and develop a distributed energy system. The system that meets the above issues could be a partly solution of the European Union's Energy and Climate Policy. This program assumes a 20% reduction in greenhouse gas emissions compared to 1990 emissions, an increase in the share of energy consumption from renewable energy sources to 20% and an increase in energy efficiency by 20% compared to forecasts for 2020 [1].

One idea is to use a cogeneration or trigeneration system on a micro, small and medium scale powered by biofuels. Systems can be divided into due of generating electric power as follows:

- Micro scale systems – up to 50 kWe,
- Small scale systems – from 50 kWe to 1 MWe,
- Medium scale systems – from 1 MWe to 50 MWe [2].

Depending on the fuel, these installations may use different executive elements. Most often these elements are Otto engines powered by biogas, fuel cells for hydrogen, an external heat source for the Stirling engine. However, these installations are expensive both during construction and operation or they are test installations.

2. Installation under examination

An alternative may be steam systems using steam machines adapted to a much smaller scale than in the case of commercial power engineering. This solution uses the Rankin cycle known from coal power plants but allows it to be supplied with different fuels depending on the selected heat source.

Heat generated during the combustion process allows to evaporate water, which is used as a working medium. Steam goes from boiler to the turbine and expands passing the blades disposed on the rotor (transfers to the rotor the part of its energy). Mechanical energy is converted to the power using a dedicated power generator. In the typical power plant, partially expanded medium goes next to the condenser what allows to utilize the heat of the condensation. An extension of classical Rankine Cycle (RC) is the Organic Rankine cycle (ORC). In ORC cycle the working medium (water) is replaced by low-boiling fluid, such as silicone oil, benzene, toluene etc. The use of organic working fluids results in the ORC cycle having several advantages over the steam cycle. Higher molecular weight than water increases the mass flow rate of the fluid for the same size of turbine. The result is a better power generation efficiency (about 10-20%). Most importantly, the boiling point of ORC fluids is much lower than that of water, so they can be applied in lower temperatures.

In the case of liquid or gaseous biofuels, the solution does not require change in RC, however for solid fuels it is beneficial to expand the system with an additional intermediate medium. The use of thermal oil cycle between heat source and evaporator will allow for increased thermal inertia, which will prevent from peak increases or decreases temperature in steam cycle. The proposed system based on the extended Rankine cycle is presented in Fig. 1.

The use of cogeneration systems equipped with the biomass-fired boilers is possible both in the case. It is really important especially in the cases, where the problems with access to the grid occur. In such facilities the oil-fired external combustion engines, which operation is really expensive are mostly used. Replacing such devices by biomass-fired CHP systems will allow reducing energy costs and obtaining full or partial energy independence [2, 3].

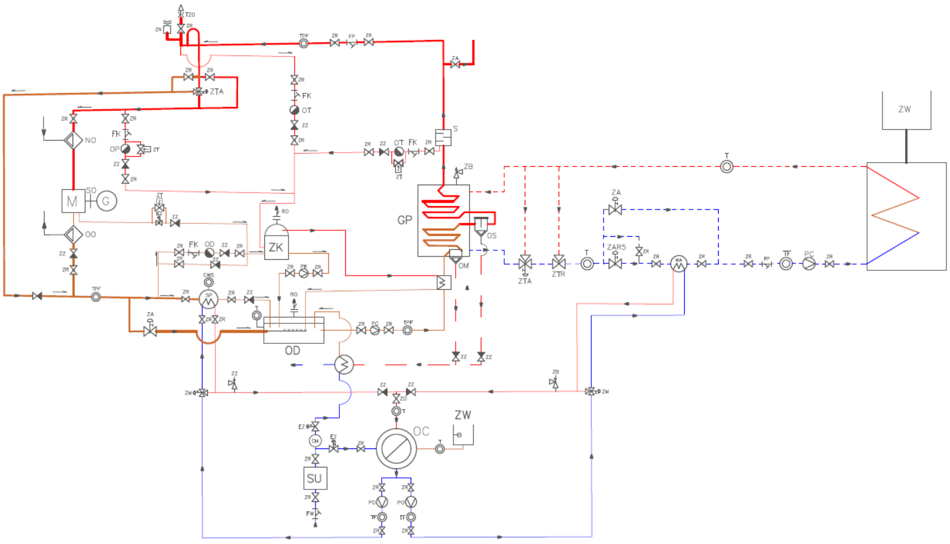


Figure 1. Diagram of a cogeneration system with a heat source in form of a straw boiler and an additional thermal oil circuit, where GP – steam generator (evaporator), M – steam machine (steam engine/steam turbine), SP – condenser, OD – degasser, OC – water tank, TPF – temperature, pressure and flow sensors, OT, OP, OD – various types of steam traps, PC, PK, PO – various types of pomps, ZR, ZZ, ZA, ZB, ZTA – various types of valves

However, the operation of this type of installation requires design experience and professional training of the operator. Occurring vibrations and hydraulic shocks can destroy individual components as well as the whole system. Steam engines and steam turbines are most exposed to vibrations, while hydraulic shocks are created by the so-called steam plugs and apply to places of condensation accumulation. The first threat results from the expansion of high pressures steam in engine cylinders or on turbine blades. They are particularly disadvantageous in the case of engines that operate cyclically. The second threat arising from the movement of the steam and condensate mixture at high speed occurs mainly on pipe sections and drainage elements themselves. Condensate pushing at high speed can also damage other system components. For safety reasons, it is important to minimize the risk of hydraulic shocks in each area of the instance, for economic and operational reasons, proper operation of the steam traps is particularly important. Detection of failure is particularly important because incorrect operation may result in condensate piling up, which results in limitation of its operation, and puncture of the steam trap may cause uncontrolled flow of fresh steam through the steam trap, which results in losses and risk of destroy condensate mains. The steam trap may also malfunction due to incorrect selection: oversizing or improper use [4]. Examples of devices exposed to vibrations and hydraulic shocks are shown in Fig. 2.

Detect of damage the steam traps and support devices can be done by:

1. Visual and auditory diagnostics

It consists of organoleptic observation of the work of individual sections of the installation with particular emphasis on steam traps. Observation of the condensate behind steam trap allows determining whether steam does not penetrate the trap, correctly drains the condensate or does not have leaks or punctures on the vent.

2. Ultrasound diagnostics

Another method is the use of ultrasound devices that give relatively clear signals of the steam trap. Ultrasounds issued during the operation of steam trap are compared with the scope of proper operation and information is sent if it is exceeded. This solution is troublesome due to the device being adapted only to selected dehydrator modes and requires each adjustment.

3. Temperature diagnostics

The third analysis option is to measure the temperature before and after steam trap. The most commonly used are pyrometers, termovision cameras or temperature sensors. At a much lower temperature behind steam trap, it can be assumed that the device does not drain the condensate properly. If the temperature difference is small, it is possible for steam to penetrate the trap.

Figure 2. Fragment of steam-condensate installation including steam turbine, steam engine and separation-drainage unit marked in red

Only a combination of all three methods, taking into account a number of operational factors, will make the assessment correct. Due to this, the method using the vibration diagnostics of the steam installation was tested [5]. Similar use for elastoacoustical materials were presented in [7, 8].

3. Results

The system is equipped with a piezoelectric sensor located on the steam turbine flange. The signal from the sensor goes to the conditioning system, and then is measured by the measuring card with a frequency of 50 kHz. A continuous spectrum analysis is carried out.

Steam impact was simulated by opening the compressed steam valve in the turbine steam supply system. This valve was located a long distance from the turbine so that the turbine received a steam blow after about 15 seconds. The steam, traversing the piping, hit the next bends of the pipeline. Figure 3 shows the next frequency characteristics for vibration measured on a steam turbine.

Analyzing the presented frequency characteristics, it can be seen that the closer the steam is to the turbine, the more visible are the frequency peaks for the range of 600-800 Hz. In the moment of steam impact to the turbine these frequencies have a higher amplitude than the vibrations associated with the normal operation of the steam installation.

The reduction of covering of the steam valve as described in [6], will reduce the vibrations on the turbine blades, and thus lengthen the lifespan.

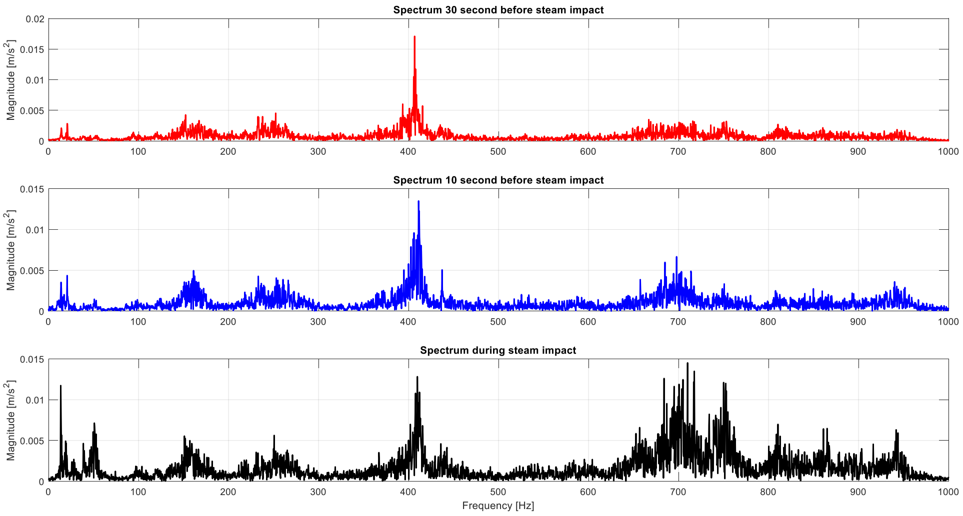
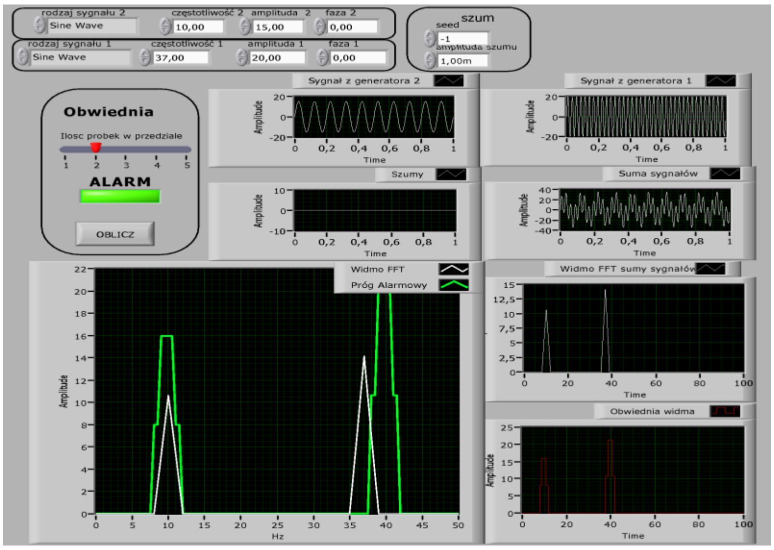


Figure 3. Diagnostic system vibration spectrum

The idea of this approach is to construct the envelope of the Fourier transform of the signal taken from the measurement. Figure 4 presents an example of the simulated envelope system. It can clearly shows the principle of operation for the measurement of the signal with two simulated frequencies. In the proposed system, the model envelope is confirmed as a reference one and the system is monitored. A change in the characteristics associated with the propagation of steam impact will result in a shift or increase in the given mode. In this case, the measured signal is going beyond the envelope boundaries. This, in turn, will entail the activation of the alarm and writing to the txt file the frequency and amplitude for which the envelope was broken.



rodzaj sygnału 2: Sine Wave
częstotliwość 2: 10,00
amplituda 2: 15,00
faza 2: 0,00
rodzaj sygnału 1: Sine Wave
częstotliwość 1: 37,00
amplituda 1: 20,00
faza 1: 0,00
szum
seed: -1
amplituda szumu: 1,00m

Figure 4. Interface of the envelope diagnostic error system

The feedback from the envelope building system allows the steam valve to be automatically adjusted by a distributed control system.

The algorithm of the envelope creator is to remove the DC bias from the input signal initially. Algorithm computes the envelope further by several steps. First is to remove the noise using the band-pass filters. First order (FIR) band-pass filters are specified by the parameter of cutoff frequencies at f_o and f_{end}. The signal is computed then using hilbert function. The Hilbert transform is useful in calculating instantaneous attributes of a time series, especially the amplitude and the frequency. The instantaneous amplitude is the amplitude of the complex Hilbert transform; the instantaneous frequency is the time rate of change of the instantaneous phase angle. For a pure sinusoid, the instantaneous amplitude and frequency are constant. The instantaneous phase, however, as is for example a sawtooth, reflecting how the local phase angle varies linearly over a single cycle. For mixtures of sinusoids, the attributes are short term, or local, averages spanning no more than two or three points. The Hilbert transform estimates the instantaneous frequency of a signal for monocomponent signals only. A monocomponent signal is described in the time-frequency plane by a single “ridge”.

The analytic signal $x = x_r + jx_i$ has a real part, x_r, which is the original data, and an imaginary part, x_i, which contains the Hilbert transform. The imaginary part is a version of the original real sequence with a 90° phase shift. Sines are therefore transformed to cosines, and conversely, cosines are transformed to sines. The Hilbert-transformed series has the same amplitude and frequency content as the original sequence. The transform includes phase information that depends on the phase of the original.

After this transformation the analytical signal is constructed. A steady state envelope is obtained by using this method.

4. Conclusions

All modern trigeneration devices require advanced diagnostic mechanisms for non-destructive testing of their condition. Such systems allow to increase their efficiency and significantly increase uptime.

This paper proposes a simple measurement system for analyzing vibrations of a steam installation. This system allows to create a frequency spectrum, which is analyzed by the envelope system. The analysis system works in a continuous mode. This arrangement allows to be included in the decision-making process by feedback for a distributed control system of the trigenerator. With this coupling it is possible to limit the impact of the steam impact by adjusting the steam supply valve. In this case, it has a positive effect on the steam turbine operation characteristics.

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