ELECTRICITY PRODUCTION WITH ZERO EMISSION AND ITS DISTRIBUTION TO THE GRID

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Abstract: To generate electricity with the minimal environmental impact is a worldwide effort. One of the options to achieve that is the using of pressure energy of natural gas during its distribution to final consumers. A gas expansion turbine is the source of the “clean” energy and it replaces throttling elements in the stations of gas reduction. Without question it is the source of emission-free energy which possibilities are not fully utilized. In the following article we will focus to selected aspects in connection with the production and distribution of power from this source from the view of power engineering.

Keywords: Stations of gas reduction, gas expansion turbine, connection to grid

1. INTRODUCTION

The using of rotating reductions is another of interesting tools for the best available technology (BAT). The reduction is widely used in the area of power engineering for example at reduction stations of water vapour and at gas reduction stations. This thermodynamic process takes place in the throttle element (valve) by isenthalpic without performance of the work. If we replace the throttle element by turbine, we can use energetic potential for example for electricity production. Steam rotational reductions are massively expanded in the area of power engineering. They are characterized mainly by simplicity and relatively low investment costs. The great potential appear in expansion back-pressure gas turbines. Sources of natural gas are usually very far from places of consumption. The natural gas must be several times reduced before its using. Therefore, gas expansion turbines can be used for power generation with advantage in the most common types of reduction stations high pressure/medium pressure (HP/MP). The electricity produced by this way is environmentally friendly because there are not any emissions during their production.

2. PRINCIPLE AND CONSTRUCTION OF GAS EXPANSION TURBINE

There are similar patterns for the transport of natural gas as for the transport of electricity in the electricity transmission grid. One of them is that the transfer takes place at a higher voltage level for the minimization of losses. The pressure loss in gas pipeline in aspect of transmitted energy is smaller for higher pressure than for higher flow velocity [9]. In the place of consumption of gas there are appliances designed for lower pressure. Therefore, it is common for the transition from the high-pressure gas pipeline (about 5 – 8 MPa) to the middle-pressure gas pipeline (400 Pa – 5 kPa) to reduce the pressure by throttle element (membrane regulator). In the suitable reduction stations (with the sufficient pressure drop and flow) it is offers the possibility of replacement of the throttle element by gas expansion turbine. It is possible to use produced electricity for own consumption of reduction station and the excess to deliver to the providers grip of distributive system.

The work obtained in the expansion turbine is proportional to the difference between admission and emission enthalpies. Process is accompanied by rapid cooling of the working medium which causes problems. The phenomenon is called the Joule-Thomson phenomenon. According to the Joule-

Thomson coefficient [1] μ we recognize whether the gas is cooled (∂p<0, ∂T<0) or warmed (∂p<0, ∂T>0) during the expansion.

$$\mu = \left(\frac{\partial T}{\partial p} \right)_H \tag{1}$$

The cooling is manifested by secreting of the liquid phase from the gas and in the extreme by frizzing of functional parts of valves. Therefore it is necessary to install appropriately dimensioned preheater in front of turbine and to adjust the gas temperature approximate to 60 °C (depending on the size of the pressure gradient).

The own principle of gas expansion turbine work is similar as at a steam turbine. The admission pressure of the medium is first transformed to velocity in a nozzle with which the gas enters under the appropriate angle on blades. Because the gas is forced by influence of blades shape to change its direction that it deduces the force to blades. This force creates torque which gives the turbine in motion.

Turbines of this type have usually one working level, i.e. the system is composed of one row of fixed (or adjustable) vanes (nozzles) and one row of blades which are stored on the wheel circumference (of action turbine) or on the drum (of reaction turbine). Shaft of a rotating wheel can be connected directly to the rotor of a generator or through a gearbox. Flow part is designed as axial or radial. The flow is controlled by turning of vanes or control valve. Mostly they are high-rotation machines (it is up to 40000 rpm). It is used a gearbox or a shaft coupling for the transformation of mechanical energy into the electricity. In case of gearbox the speed of the generator are usually 3000 rpm. In case of shaft coupling the high-frequency is generate which is necessary to convert to grid frequency. The example of radial gas expansion turbine is in figure1.

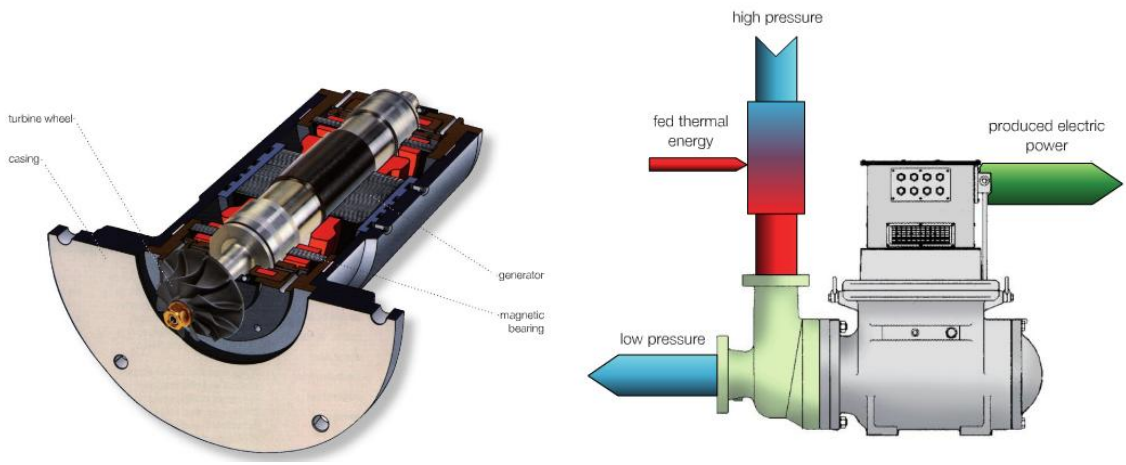

Figure 1: Radial gas expanse turbine [6].

3. INCLUSION OF TURBINE TO REDUCTION STATION SCHEME

The arrangement of stations should be chosen with regard to continuity of supply to consumers. Therefore, gas expansion turbines are installed always parallel to the conventional throttle line. The expansion turbine is situated as master and line with convention throttle element is situated as redundant [3].

The general scheme of reduction station with expansion turbine is shown in Figure 2. The medium from the high-pressure gas pipeline is preheated in a vertical pipe exchanger. Then the pipe is divided into operational and redundant line. The redundant line is equipped with an emergency stop-valve, regulator and with overpressure valve. The master line of expansion turbine contain the emergency stop-valve, control valve (emission pressure of the gas is possible to control by turning of vanes), turbine and overpressure valve. The emergency stop-valve is activated when the nominal speed of turbine is exceeded approximately about 10 % or there is impressing of reverse power, overvoltage and under voltage protection. Next the activation of the emergency stop-valve can be caused by under frequency or over frequency protection or the intervention of service (stop button).

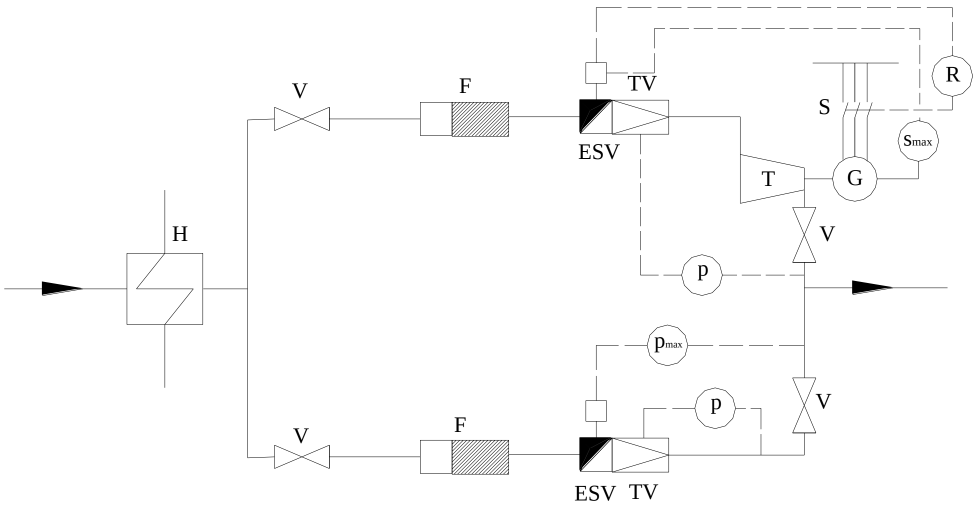

Figure 2: Inclusion of turbine to reduction station scheme (H-heater; V-valve; F-filter; ESV-emergency stop valve; TV-throttle valve; T-turbine; G-generator; R-relay, p-pressure; S-switch; s_{max}-speed max.; p_{max}-pressure max.).

4. PARALLEL OPERATION WITH DISTRIBUTION GRID

The parallel operation of these sources in medium voltage (MV) or high voltage (HV) grid controls the provider of distribution grids (PDG). There are solved mainly changes of voltage caused by permanent operation of production, changes of voltage during the switching, attenuation of mass remote control, quick changes of voltage (flicker), the contribution to level of higher harmonic currents etc. The largest technical problem is to connect a larger generator (in order of MW) to the grid with small short-circuit powers. This leads to an undesirable influence of quality parameters (for example voltage) in this grid. Programs are used for the calculation. These programs used basic iteration methods for calculation of steady state in the grid. This means that they calculate the distribution of voltages and currents in the nodes and in the branches of grid. The Newton method is the iteration method [7] which is often used for this.

$$\begin{bmatrix} [\Delta P] \\ [\Delta Q] \end{bmatrix} = \begin{bmatrix} \left[\dfrac{\partial P}{\partial U}\right] & \left[\dfrac{\partial P}{\partial \delta}\right] \\ \left[\dfrac{\partial Q}{\partial U}\right] & \left[\dfrac{\partial Q}{\partial \delta}\right] \end{bmatrix} \cdot \begin{bmatrix} [\Delta U] \\ [\Delta \delta] \end{bmatrix} \qquad (2)$$

For the calculation it is necessary to know the configuration of the grid: switching stations (voltage level, short-circuit power), transformers, transmission lines (their types, length, etc.), bleeding points (active and reactive consumption) and last but not least, parameters of the connected source.

For the assessment of the voltage level in distribution grids it is important to respect two element states. The first state is the grid which is strongly loaded with a minimal number of sources. It logically leads to the fact that there is low level of voltage. The second state is the grid with small load (low loaded) but on the opposite with large number of sources. In practice there are the most often noticeable these extreme at dispersion sources. Therefore, there is often problem with compliance of prescribed voltage tolerance in these grids. This issue is deal in one chapter at rules of operation of distribution grid where is said: The increase of voltage caused by operation of connected sources cannot in the worst case exceed 2 % for the production with the connection point in the grid of HV and 110 kV. For the production with connection point in the grid of MV it is 3 % in compared with the voltage without their connection.

4.1. POWER OUTPUT FROM GENERATOR

The high operating speed is the common feature of compact expansion turbine. Therefore, with regard to size and the losses there are not used reducers but there is direct connection the of gas expansion turbine rotor with the high speed generator. It is used synchronous generator excited by permanent magnets. For the connection to the distribution grid it is necessary to insert a frequency convertor between generator and outlet to distribution grid. The disadvantage is that these semiconductor elements emit nonsinusidal (nonharmonic) current to the grid. Elements of the distribution grid – transformers, transmission lines and compensating devices are dimensioned for nominal frequency of the grid (50 Hz). Higher harmonic currents in grids cause losses. Nonharmonic currents cause nonharmonic drops of voltage and thus it leads to the deformation of the voltage in distribution grid. The deformed supply voltage can affect sensitive appliances (control systems, etc.). For a minimization of higher harmonic unites it is necessary to installed filters. The power outlet is shown in blocks in Figure 3.

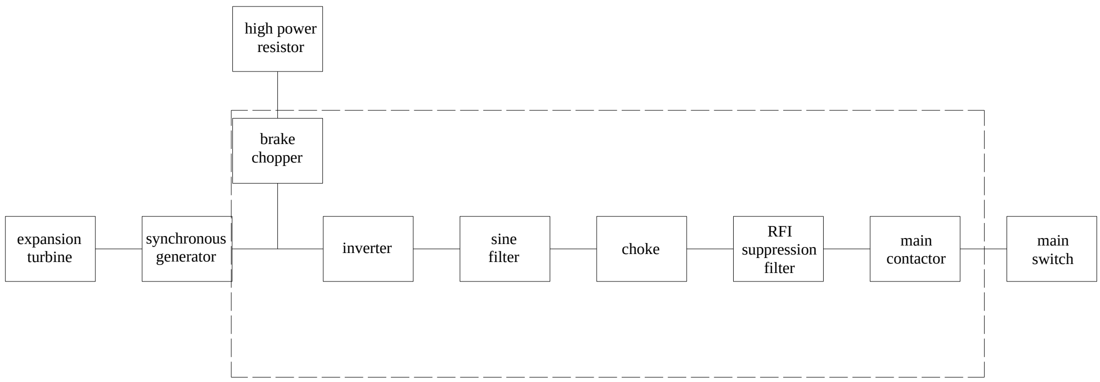

Figure 3: Block scheme of frequency convertor and power outlet to grid.

5. ECONOMIC ASPECT

For the objective evaluation of the investment efficiency it is necessary to perform the sensitivity analysis [8]. The analyse of the sensitivity is the impact of changes of chosen input values to the profitability of a project. In this case the investment depends primarily on the high acquisition costs, low purchase price and on the costs associated with the need to preheat the medium.

High investment costs are the cause of the small expanding. Therefore devices are designed and constructed according to customer. Due to the constantly rising energy costs the gradual “replacement” of static throttle elements should be promoted as an environmentally friendly source of electricity by increased purchase price of electricity. It is also necessary to take into account the fact that the preheating is required even in conventional reduced gas stations, and that most of installations allows recuperation of the waste heat.

6. INSTALLATION EXAMPLES

There are only few producers at the market who are engaged in the production of expansion turbines. In the Czech Republic they are made by company G-Team and in the world it is for example company Siemens AG, ABB and RMG Regal+Messtechnik GmbH.

According to available information [5] in the Czech Republic there are two gas expansion turbines in the commercial operation. One of them is the turbine with maximal power of 1.56 MW installed at the reduction station HP/MP dimensioned for the maximal flow of 30000 $m^3 \cdot h^{-1}$ in Brno. Second unite is installed in the pre-regulation station in Velké Němčice with the nominal power of 1.2 MW which is made by ABB.

Gas expansion turbines are used as starting devices in our republic. To start of combustion turbines for drive the turbo-compressors in compress station of natural gas is used mainly for the independent of the external power grid. The starter turbine is driven by bleeding from the transit gas pipeline. The disadvantage is that the gas is emitted into the atmosphere after the expansion.

7. CONCLUSION

Theoretical potential of the emission-free production of electricity in gas expansion turbines is large, especially when we realize that in the Czech Republic are thousands of gas reduction stations. It is important to take into account technical and economic aspects, which some of them were remembered in this article.

As the main obstacle of massive expansion these interesting plants seems to be Joule-Thomson phenomenon. This phenomenon is applies more or less in every reduction of gas pressure. Especially for natural gas there is a decrease of temperature. The problem is that during the expansion in the turbine may temperature drop up to 40 °C for the reduction of 1 MPa. While during the throttling in the common throttle element there is the decrease only about 10 °C. Large energetic requirements for preheating of the gas are possible to reduce by recuperation of waste heat.

In the case of fitting the gas reduction station by expansion turbine it is necessary to connect it in parallel redundant convention control line. The power of the expansion turbine is directly proportional to the mass flow of the gas. Therefore, it is important to properly choose the place of installation, i.e. near the big appliances with small change of power. In terms of outlet of power to the distribution system it is necessary to mention the potential increase of voltage caused by constant operation of source which cannot be higher than 3 % for MV and 2 % for HV, and the emission of higher harmonic current if the high-speed turbine without gearbox is used.

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