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COMPUTER MONITORING AND CONTROL SYSTEM OF A LOCAL LNG SUPPLY STATION

KOMPUTEROWY SYSTEM MONITORINGU I STEROWANIA LOKALNEJ STACJI ZASILANIA LNG

A b s t r a c t

This paper presents a proposal of computer system to support the work of local LNG supply station. The main advantages of proposed system are to increase safety and reduce the operating costs of the station. On the basis of preliminary analysis the main functional modules of the system have been distinguished. The modules include: vaporization control unit, subsystem for monitoring parameters in the cryogenic tank and installation, central database server, data visualization module, diagnostic subsystem and module for LNG supplies optimization. The system has been used for investigating a real supply station.

Keywords: *LNG*, *monitoring*, *internet application*, *software development*

S t r e s z c z e n i e

W artykule przedstawiono propozycję systemu komputerowego wspomagającego pracę lokalnej stacji zasilania LNG. Do głównych zalet wprowadzenia systemu należą zwiększenie bezpieczeństwa oraz zmniejszenie kosztów użytkowania stacji LNG. Na podstawie przeprowadzonej wstępnej analizy wyróżniono główne moduły funkcjonalne: moduł sterowania procesem parowania LNG, podsystem monitoringu parametrów w zbiorniku kriogenicznym i instalacji, centralny serwer bazy danych, moduł wizualizacji danych pomiarowych, system diagnostyki oraz moduł optymalizacji dostaw surowca. System został wykorzystany do przeprowadzenia badań rzeczywistej stacji zasilania LNG.

Słowa kluczowe: *LNG*, *monitoring*, *aplikacja internetowa*, *budowa oprogramowania*

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Denotations

t	– time [s]
q, q_1, q_2	– LNG evaporation rate [kg/(m^2 s)]
k, k_1, k_2	– coefficient of evaporation [J/(m s K)]
T_s, T_1	– ambient temperature, LNG temperature [K]
ρ, ρ_1	– density [kg/m3]
ΔH_V	– latent heat of evaporation [J/kg]
c_p	– specific heat capacity [J/(kg K)]
α, α_s	– heat dissipation factor [J/(m2 s)]
β	– coefficient of cubical expansion [1/K]
ν	– kinematic viscosity [m2/s]

1. Introduction

A typical LNG supply station consists of a tank where a natural gas is stored in a liquefied form. Maintenance of the gas requires temperature of minus 160 degrees Celsius, so the tank must have a construction, which minimizes heat leakage [9, 10]. Total elimination of the leakage is not possible, therefore inside of the cryogenic tank there is a liquid phase and a certain amount of a gas phase, resulting in the evaporation process [3, 4]. At low gas consumption, amount of the gas phase may be sufficient to supply the appliances. If gas consumption is higher, it is necessary to use an appropriate system of vaporizers. This approach allows to manage resource rationally, however, requires the use of two independent transmission systems with an adequate switching mechanism [2]. This mechanism can be implemented by means of automatic control, provided that the current values of parameters such as pressures, temperatures, flow rates are known. Therefore, the control system must be connected with the monitoring system. Authorized personnel of the supply station should have permanent access to the current values of the parameters using a PC computer or a mobile device with Internet access. Furthermore, the personnel must be immediately informed in case of any emergency or unusual situation. This requires access to a relational database which holds data from sensors [7]. These data will also help to optimize delivery of LNG on the basis of consumption rate in the previous time period.

Analysis of presented requirements has led to the development of a computer system that will increase safety and improve the work of a local LNG supply station.

2. Models of LNG evaporation process

Operation of a local LNG supply station is based on the LNG evaporation process. Study of LNG vaporization were carried out by many academic, research and industrial centers, among others by Kelly-Zion, Pursell, Booth and VanTilburg [8], the American Gas Association, Drake and Reid [5], Opschoor [11], Bryson [2]. On the basis of evaporation of liquid methane Zabetakis and Burgess developed a model which describes an evaporation rate at the initial stage of the process [12]. They found that the rate is limited by the supply of heat from the environment and is given by the formula:

$$q = \frac{k}{\rho_1 \cdot \Delta H_V} \frac{T_s - T_1}{(\pi \alpha_s t)^{1/2}} \tag{1}$$

This formula is applicable only in the initial stage of evaporation, not exceeding the time of one minute after the start of the process. Double logarithmic plot of evaporation rate against time has the form similar to a straight line. LNG evaporation process has been particularly thoroughly studied by Drake and Reid [5]. They conducted a series of experiments in relation to the results obtained by the American Gas Association and Gaz de France. They demonstrated the following formula:

$$q = A_V \cdot t^{-1/2}$$

where the evaporation coefficient A_v should be determined experimentally. V.J. Clancey [6] also developed a model describing the evaporation of cryogenic liquid such as LNG. Rapid evaporation in the initial period of time has been described using the following formula (k_1 and k_2 coefficients are determined experimentally):

$$q_1 = \frac{k_1 \cdot (T_s - T_1)^2}{\Delta H_V} \tag{3}$$

while in the steady phase:

$$q_2 = \frac{k_2 \cdot (T_s - T_1)}{\Delta H_V} \tag{4}$$

Rate of the LNG evaporation process was studied by S. J. Turner. Based on the results of his research G. Opschoor formulated the following mathematical formula [6, 11]:

$$q = 0.085 \cdot k \cdot \left(\frac{g \cdot \beta \cdot \Delta T^4}{\alpha \cdot \nu} \right)^{1/2} \tag{5}$$

For the LNG, on the basis of the above equation, the following heat flux value can be obtained: q = 2.3 · 10^4 [W/(m^2s)], what leads to the mass of the evaporating LNG: m = 0.045 [kg/(m^2s)]. Presented Opschoor's model was used in the development process of the LNG vaporization control unit.

3. Concept of a control and monitoring system

A typical LNG supply station contains the following components: a cryogenic tank for storing LNG, a vaporizing installation, transmission system with safety valves and installation of pressure reduction. First step of the analysis was to identify measurement points. The distinguished points are presented in Fig. 1.

As can be seen from Fig. 1, the following parameters of the LNG supply station will be subject to monitoring: P1 – LNG vapor pressure inside the cryogenic tank, VG1 – vacuum level between walls of cryogenic tank, T1, T2, T3, T4 – temperatures, respectively: at the outlet from the tank, before and after the pressure built unit (PBU), ambient temperature, F1 – loss of LNG through the safety valve, F2 and F3 – mass flow before and after the pressure built unit (PBU), F4 – LNG consumption.

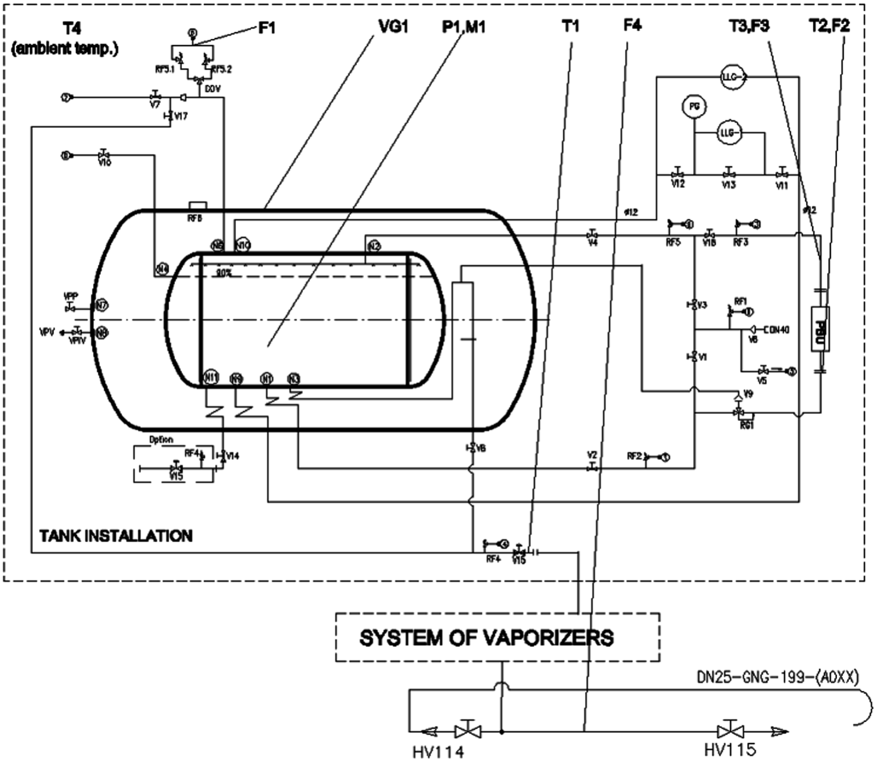

Fig. 1. Installation of a local LNG supply station with measurement points

Rys. 1. Instalacja lokalnej stacji zasilania LNG z punktami pomiarowymi

3.1. System requirements and main functionalities

Some prerequisites were taken into account at the start point of the system development. Due to the diversity of functionalities, it was decided to decompose system into modules. Individual modules have the form of desktop applications or applications running under internet browsers. Desktop applications run in Microsoft Windows system, while the internet applications are available for browsers on any operating system, including mobile devices, smartphones, tablets, PDA etc. Application for acquiring the measurement data supports typical DAQ Advantech cards. The measurement data is stored in a relational client server database Firebird.

The system should allow to acquire data from the transducers and store in a database for later processing and analysis as well as allow to control selected systems of the installation remotely by authorized personnel. The user should be able to observe time courses of selected parameters in both numerical and graphical form. Secure remote access to data via the internet should be provided. The operator should have an access to messaging and alerting system including short text messages (SMS) and e-mails. The system should allow to optimize delivery of the LNG to the local supply station on the basis of the real-time consumption analysis.

3.2. Deployment diagram of the system

On the basis of the analysis, the following components of the system have been extracted: monitoring subsystem, relational database server, visualization and diagnostic module, control module and subsystem of the LNG delivery optimization. Fig. 2 presents relations and dependencies between individual components.

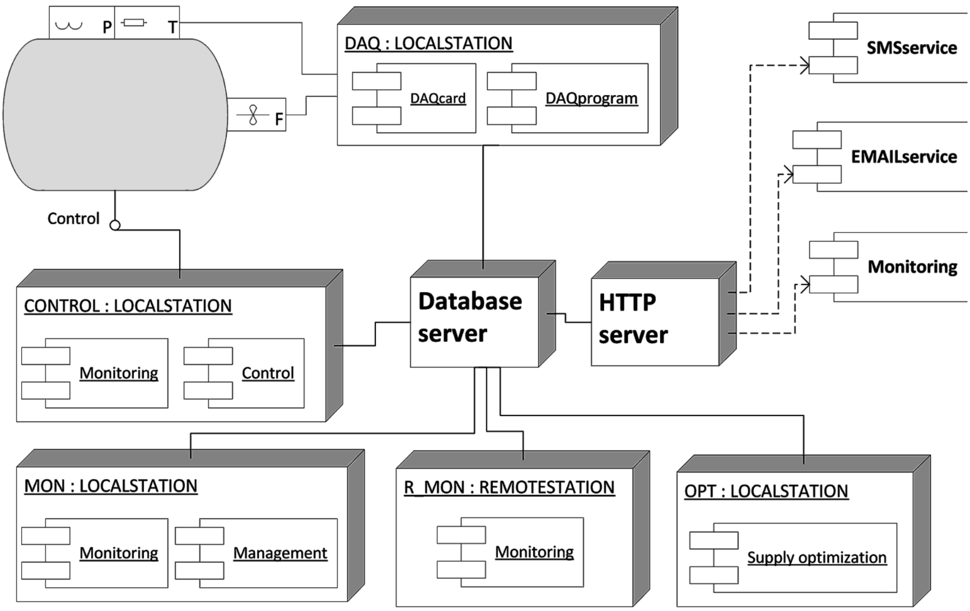

Fig. 2. Deployment diagram of the system

Rys. 2. Diagram wdrożenia systemu

As arises from Fig. 2, the monitoring subsystem includes sensors and transducers, DAQ card and a program for data acquisition implemented in a local station DAQ. Programs for management of monitoring parameters (i.e. frequency of readings from the transducers, measuring ranges, scaling parameters of the signals [1]) are implemented in local station MON. Relational database server is a central element of the system, almost all other components are connected with it. Visualization and diagnostics module can be used locally by a desktop application (local station MON) or remotely, using internet browsers (remote station R_MON*)*. Remote diagnosis includes sending messages, warning and alerts via SMS and e-mail. The control unit, for safety reasons, may be used only by authorized personnel on local computer CONTROL. The optimal schedule for the LNG delivery is determined by a separate application which is installed locally on the OPT station.

4. Implementation and presentation of the monitoring subsystem

As a practical example of system implementation, a monitoring subsystem will be presented. Hardware diagram of the subsystem is presented in Fig. 3.

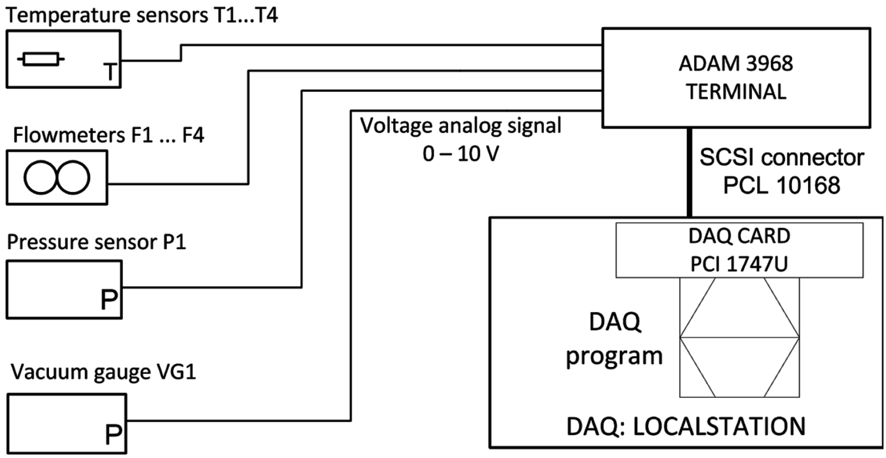

Fig. 3. Diagram of the measurement system in the monitoring module

Rys. 3. Schemat układu pomiarowego w module monitoringu

Proposed measurement system includes sensors with analog signals and a DAQ card with the A/D converters [1]. A standard SCSI connector is used for communication between the DAQ card and ADAM-3937 terminal. A DAQ program allows to acquire data and present it in a graphical form. The program was developed using C# language.

Main functionalities of the program available to a user are presented in the UML use case diagram in Fig. 4. The diagram shows the three main use cases available to the user of the program: configuring program parameters (*Config*), performing the measurement (*Measurement*) and the presenting values of the most recent measurements (*On-line presentation*). The configuration is done using the input and output settings (*I/O settings*) as paths, initialization files, output file formats, location and access parameters to the database. The configuration process also may include settings of the data acquisition card (*DAQ config*) as well as settings of the measurement channels (*Channel calibration*). Each measurement channel has an individual range, a gain coefficient and a zero-point value (*Channel calibration*). Use cases *DAQ config* and *Measurement* utilize the Advantech API interface. Furthermore, the *Measurement* uses a database connection interface. Results of the most recent measurements can be presented in a numerical format (*Numerical*) or as a function against time (*Graphical*).

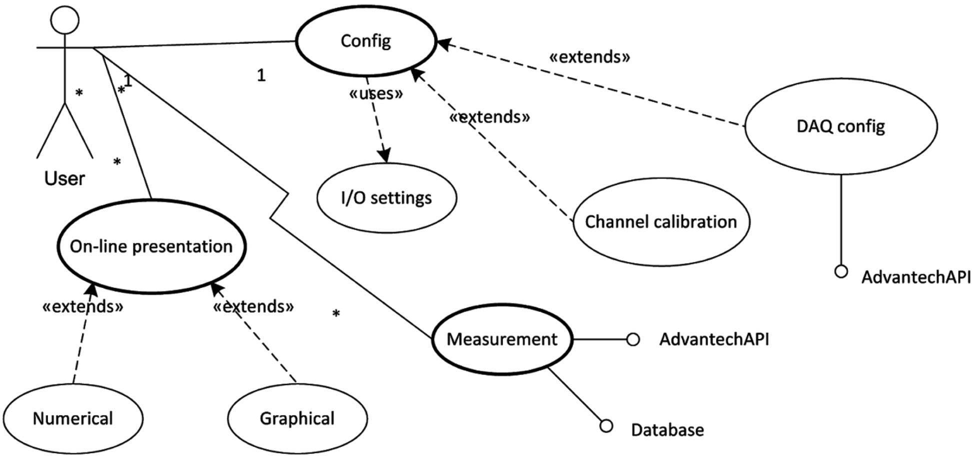

Fig. 4. Functionalities of the monitoring subsystem in the use-case diagram

Rys. 4. Funkcjonalności podsystemu monitoringu na diagramie przypadków użycia

The data acquired by the monitoring subsystem and stored in the database can be used to create plots against time of selected parameters. In Fig. 5 is presented example time chart of a pressure inside the cryogenic tank obtained during experiments.

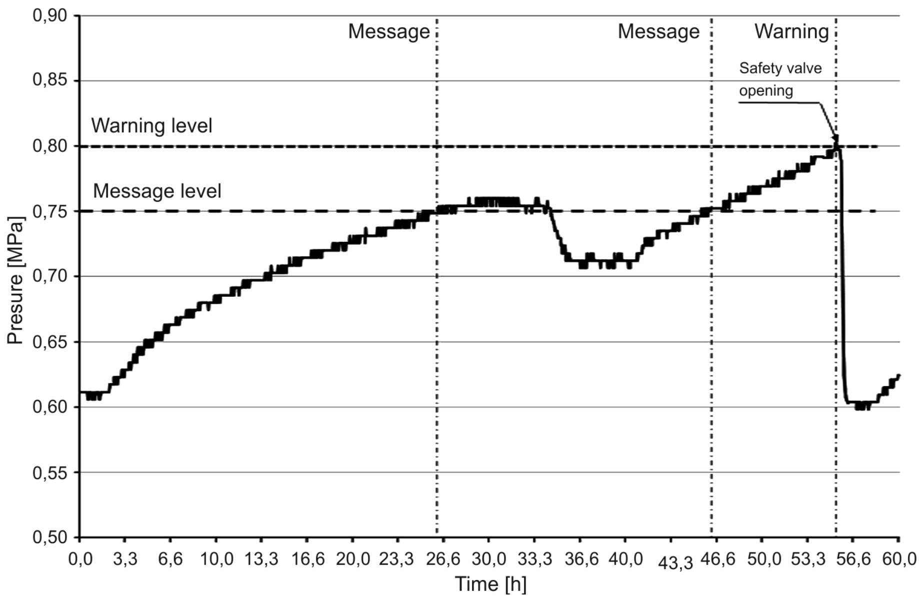

Fig. 5. Time chart of the pressure with times to send messages and warnings

Rys. 5. Przebieg ciśnienia z zaznaczonymi momentami wysyłania wiadomości i ostrzeżeń

In presented time period value of the pressure was rising from 0.61 MPa to 0.76 MPa during first 27 hours and then stabilized. At time 35.0 it started to decrease due to the increased consumption. From time 41.0 it raised again and reached the message level at time 34.0 and then warning level at time 55.5. Then the safety valve was opened, what resulted in rapid pressure drop to the value 0.6 MPa. It can be observed from the figure, that one warning and two messages were sent to the operator. The appropriate algorithm avoids sending messages when value of the pressure decreases (time points 34.0 and 56.1).

5. Conclusions

Presented system of control and monitoring of a local LNG supply station allows to significantly improve safety and reduce operational costs. The system is complex and extensive, includes several modules designed for different purposes, i.e. control, monitoring, visualization, optimization, messaging, alerting. In terms of practical applications, the monitoring subsystem was used in Chemet company for testing new generation of cryogenic tanks. Next, it is planned to implement the system in local LNG supply station in Bukowina Tatrzanska.

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