PAPER • OPEN ACCESS

The Development of Solar-Powered Gas Metering Units Equipped with Radio or 3G Based Telemetry Systems

To cite this article: M A Velichko *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **791** 012060

The Development of Solar-Powered Gas Metering Units Equipped with Radio or 3G Based Telemetry Systems

M A Velichko, Yu P Gladkikh and I B Kostina

Department of Computer Science, Natural Sciences and Teaching Methods, Belgorod State National Research University, Pobeda St., Belgorod, 85, 308015, Russia

E-mail: velichko@bsu.edu.ru

Abstract. In this article we have described the development of solar-powered gas metering units including modern ultrasonic and vortex flowmeters for volume and mass measurement of natural gas, associated petroleum gases, inert gases, oxygen, hydrogen, air, nitrogen, carbon dioxide and any other single and multicomponent gases that are not aggressive to the flowmeter materials. We have shown implementation of such units in the existing gas producing stations in the desert of Kara-Kum. Confirmed was the ability of our gas metering units to operate more than a year without network power supply and staff intervention. Also pictured was creation of telemetry system for collecting and transmitting metrological information, including gas flow rate, temperature, pressure, humidity to the central terminal. Different physical layers have been used to transfer data from the metering units, including radio channels at 433 MHz frequency between units and central station. This telemetry system implemented self-maintenance and self-monitoring features, facilitating remote control of metering unit, so important in rigid conditions of solar-rich deserts and semi-deserts.
Key words: solar energy, telemetry, gas flow rate, gas metering unit, Web Socket

1. Introduction

Natural gas of Central Asia and Transcaucasia has long played an important role in meeting the needs of the domestic market of Russia, countries of the Commonwealth of Independent States and also far abroad. Russia plans to continue gas purchases in Central Asia and Azerbaijan, strengthening its position in this region [1].

Kazakhstan, Turkmenistan, Uzbekistan and Azerbaijan are also objects of increased interest from China, whose energy consumption has enlarged significantly due to the growth of industrial production. China also plans to increase its influence in this market, catching up profit that was lost in the Soviet period [2].

In Central Asian countries, gas pipelines are often laid through such areas as deserts or semi-deserts, that are difficult to access for electrical networks. Gas metering units and gas-distributing stations are spatially spaced and in most cases it is expensive to maintain and monitor them. Even if metering units are located within the reach of electrical lines, sandstorms and other weather and technogenic conditions can often lead to power supply failures.

The Central Asian region is also rich with oil, where production meets the same power and maintenance problems. In some countries infrastructure has not been seriously modernized since the Soviet Union. We propose the combined approach that can significantly relieve metering units monitoring and dramatically reduce power consumption so that constructing or upgrading existing power infrastructure in many cases will not be necessary.

The main origin of such approach is that Central Asian region has no shortage of solar energy. The annual duration of sunlight here is 2200-3000 hours per year, and the estimated power is 1300-1800 kW per 1 square meter per year. This is enough for the construction of efficient solar power stations. And, of course, it is more than enough to maintain the smooth operation of gas metering units. Mobile networks are deployed along gas and oil transportation routes and face minimum technological difficulties (besides they are rather modern), so remote metering units monitoring can almost substitute necessity of specialists' presence in the fields. In cases when metering units are by some reasons out of mobile network coverage, radio channel transmission can be organized.

So the aim of our work was to develop a solar powered gas metering unit equipped with the telemetry system, that in its turn, could transmit metrological data to the remote terminals and could also provide self-maintenance features. This unit should be able to measure and control gas flow rate under different conditions. The whole system should be energy effective and robust in the rigid conditions of desert and semi-desert. These units should include flowmeters able to measure flows of natural gas, associated petroleum gases, inert gases, oxygen, hydrogen, air, nitrogen, carbon dioxide and any other single and multicomponent gases that are not aggressive to the flowmeter materials. That is, it should be able to cover the entire spectrum of gases produced in Central Asia, as well as in most other solar-rich regions. It could also be used in oil production process, e.g. measuring associated petroleum gas in gas-lift methods.

Figure 1. The model of solar-based gas metering unit using IRGA-Helio flowmeter.

2. Materials and Methods

IRGA-TS telemetry system was developed and used to monitor and automate gas and power consumption at the fields of Turkmenneft group. Ultrasonic and vortex IRGA gas meters with software were installed at the wells in "Goturdepenebit" oil and gas production unit. Gas was used in the gas-lift method of well operation, which is a logical continuation of the fountain method of oil production. The missing amount of associated petroleum gas for oil recovery was pumped into the well from the surface. It was necessary to constantly monitor the temperature, pressure and volume flow of gas, as well as remotely control solenoid valves and gates for effective management of oil production in wells.

For operation of gas lift valves in the conditions of the field, compressed gas was supplied from the compressor station with a maximum (peak) pressure of 8.0 MPa. In order to comply with safety conditions, a safety margin of K = 1.25 was accepted. So the flowmeter sensor was designed for pressure P = 8.0 x 1.25 = 10.0 MPa. This requirement was fulfilled by the sensor of the PDTVH-1Eh-02-10,0 MPa mark No. 12-03369 installed in 2 wells of the field.

Solar-powered version of IRGA flowmeters was called IRGA-Helio (Figure 1). It implemented the solar panel as a power source, that converted light energy into electricity, and a battery that stored that energy. One not very sunny day of battery charging at the latitude of the device homeland – Belgorod – was enough for continuous operation of the metering unit for two days. The solar panel had a small size and was placed in a strong aluminum frame with structured tempered glass.

The design of the gas metering unit allowed us to expose the panel at an optimal angle to the solar flow for fast battery charging. The helium batteries installed in the system had high temperature stability and high power output, as well as good recovery after deep discharge. The controller maintained the energy system. It didn’t not allow its overload or reverse current at night.

All elements of the system had a very high service life and had been tested for a long time in various climatic conditions. IRGA "Helio" could operate without human intervention for months, sending the necessary information about the parameters of the gas environment with the help of a telemetry system.

Telemetry is an automated communications process by which measurements and other data are collected at remote or inaccessible points and transmitted to receiving equipment for monitoring [1]. Systems that need external instructions and data to operate require the counterpart of telemetry, telecommand [2].

Although the term commonly refers to wireless data transfer mechanisms (e.g., using radio, ultrasonic, or infrared systems), it also encompasses data transferred over other media such as a telephone or computer network, optical link or other wired communications like power line carriers. Many modern telemetry systems take advantage of the low cost and ubiquity of GSM networks by using SMS to receive and transmit telemetry data.

A telemeter is a device used to remotely measure any quantity. It consists of a sensor, a transmission path, and a display, recording, or control device. Telemeters are the physical devices used in telemetry. Electronic devices are widely used in telemetry and can be wireless or hard-wired, analog or digital. Other technologies are also possible, such as mechanical, hydraulic and optical.

Telemetry may be commutated to allow the transmission of multiple data streams in a fixed frame.

Different telemetry systems used in metrology are described in [1-6].

To measure the volume flow rate of associated petroleum gas, full-pass vortex flow meters with nominal flow diameters from 50 to 200 mm were selected. The vortex motion in such flow meters is provided by a flow body located in the path of the moving flow, which in the cross section has a shape close to the trapezoid. The system of vortices arising behind this obstacle is called the Karman vortex path, and the frequency of the collapsing vortices in the first approximation is proportional to the flow velocity [8]. The flow rate, in turn, allows to calculate the gas flow rate under operating conditions with an accuracy of 1%. The conversion of the flow rate into operating conditions into a unified flow rate under standard conditions was carried out in the computing device, which received the necessary metrological data from the pressure and temperature sensors. These sensors were located in the pipeline together with the flow meters.

Given the instability of electricity metering units, as well as the abundance of solar energy in the desert, instrumentation cabinets were equipped with autonomous power supply from solar panels (panel controllers and batteries were also installed in instrumentation cabinets).

For effective management of the gas lift process, monitoring of metering stations and control of associated gas flows had to be carried out continuously and without interruptions. Also, for the full automation of the process in the future, a thorough analysis of the accumulated statistical data was required, for which a detailed archiving of the transmitted metrological information was necessary [9].

3. Results

The data was transmitted to the server via the Internet. HTTP and Web Socket protocols were used as the application layer protocols. Users with the appropriate access rights, using modern Web-browsers sent GET-requests to the server. The server stored various temporary archives that contained all the information necessary for monitoring and decision-making (environment temperature, air, gas temperature, atmospheric pressure in the area of the well, pressure drop at different points of the pipeline, the presence or absence of electricity, battery charge, occurrence and description of emergency situations, etc.). These archives were sent to the server by POST requests from the computing devices located in the accounting nodes. POST requests were formed automatically in accordance with the established time schedule [10]. Thus, the server had two types of clients: web-browsers of telemetry system users and special software of the client device developed by our group.

The module developed by our group was used as a transmitting POST-requests device, which was installed in the control point at a distance of no more than 10 km from each of the wells. This IRGA-LT device served as an intermediate between the accounting nodes and the server. It included a 3G module controlled by a special microcontroller with the help of automated AT-commands. It was decided not to install similar 3G modules in each metering station due to 3G communication failures in the vicinity of the fields and the need to pay for and maintain SIM cards, as well as to simplify the transmission system.

Each metering point contained another self-developed device IRGA-NT connected to the computing device using UART protocol. Transfer of data from IRGA-NT to IRGA-LT was carried out via 433 MHz radio frequency [11]. Code and time modulation was used. Each radio module placed in the unit IRGA-NT, was assigned its own unique number, and the data was passed in turn from each node after the receipt of the request from the IRGA-LT radio module. In case of transmission errors signals of emergency situations were generated.

Both IRGA-LT and IRGA-NT radio-boards implemented E32-TTL-100 (Figure 2) boards with power of 100 mW, that were able to transmit and receive data over more than 10 km in the desert without additional amplifiers. It was possible to use such range of frequencies at such power according to special administrative permissions in Turkmenistan. Despite its high-distance transmission E32-TTL-100 had ultra-low power consumption of about 30 μA. It also offered broadcast transmission that was useful when data had to be transferred from IRGA-LT to all IRGA-NTs.

Figure 2. E32-TTL-100 radio board as electronic part of IRGA-LT and IRGA-NT modules.

When creating models of IRGA-NT and IRGA-LT devices, AVR microcontrollers installed in Arduino boards (UNO for IRGA-LT and NANO for IRGA-NT) were used to control the operation of radio modules, 3G modules and other electronic components. Arduino board software was developed in the Arduino IDE in the C++ programming language [12].

The server contained a PHP file to handle requests from the client IRGA-LT, as well as the HTML page passed as the response to the Web browsers. These HTML pages used JavaScript language, especially for a periodic AJAX poll to the server to inquire if the new data from IRGA-LT had arrived.

We have recently developed the new industrial time-of-flight ultrasonic gas flow meter IRGA-RU that has already been entered into the State register of measuring instruments [13].

Its operation principle is based on the time-to-pulse method of gas flow measuring. It consists in measuring the time of ultrasonic pulses passage in the direction of the gas flow in the pipeline and against it. Excitation and reception of pulses is carried out by piezoelectric transducers, which are installed in an all-metal case of the flowmeter at an angle (from 30° to 45°, depending on the version) to the flow direction. The speed of ultrasound in the medium depends on the physical and chemical properties of this medium: temperature, pressure, etc. At the same time, it is much greater than the speed of the medium, so that the actual speed of ultrasound in a moving medium is not much different from its speed in a stationary medium. The difference in transit times Δt even at flow rates of about 10 m/s is a fraction of a microsecond, while the measurement error should not exceed a few nanoseconds [14].

These circumstances necessitate the use of complex electronic circuits in combination with microprocessor technology, providing compensation for the influence of these factors.

Structurally, the flow meter consists of three blocks:

- primary flow converter, which is a housing with built-in ultrasonic transceivers;
- electronic unit, which carries out the reception and transmission of signals through ultrasonic transceivers, their conversion, processing and calculation of the volume flow of gas under operating conditions, followed by the formation of the output signal;
- power supply unit with built-in spark protection barrier to provide explosion protection circuits if necessary.

The electronic unit controls ultrasonic transceivers, performs receiving, processing, converting and transmitting signals to the computing device. These signals contain, in particular, information about the propagation time of the ultrasonic pulses, that is required to calculate the volumetric gas flow rate in operating conditions [15].

4. Discussion

The design of flow meter eliminates the possibility of unauthorized influence on the flow meter software and measurement information. We have developed and successfully tested our own control circuits for piezoelectric transceivers, and also created new original algorithms for processing received signals [16].

It allowed us to

- significantly expand the dynamic range of gas flow measurement to values of the order of 1:2000; increase the accuracy of measurements to 1% in most tasks;
- use our flowmeter on pipelines of almost any diameter;
- measure the flow rate of various physical and chemical properties of gas media;
- carry out measurements at high speed, in a wide range of temperatures and pressures;
- not to introduce additional pressure losses into the pipeline.

At the same time, our flow meter has a fairly simple design and does not require significant lengths of straight sections before and after its installation.

We have also mastered and successfully tested the technology of applying anti-adhesive coating on the inner walls of the flowmeter to avoid sticking of the solid fraction of the measured medium. This helped us to reduce the probability of non-reproducibility of measurement results by 0.2% [17]. In future it will also lead to calibration interval decrease.

In our flowmeter design we have used modern time-to-digital microcontroller convertors, that apply energy saving technologies. We have also developed energy efficient algorithms of transmission, receiving and processing of ultrasonic pulses. Power consumption has decreased to several μW. It helped us to implement autonomous power supply from rechargeable batteries.

Our colleagues from Turkmenistan gave us a possibility to test our device powered by solar panels in desert conditions with almost cloudless weather and periodic changes in energy supply. Experiment has shown that our flowmeter is able to operate without direct maintenance for months [17].

Information from IRGA-RU was transferred to the computing device and then transmitted via above described telemetry system. The same system was also used to unite our flowmeters into the network.

5. Conclusion

We have developed and effectively tested the solar-powered metering unit with telemetry system in a set of applications and conditions. No extra power except solar power was needed to maintain the system.

According to Turkmenneft report the use of flowmeters was effective for accounting for the flow of the working agent (gas) and calculation of associated gasin order to increase oil production from a certain category of wells currently operated by the gas lift method.

A significant reserve for improving the efficiency of the use of metering of the working agent (gas) and calculation of associated gas was to improve the selection of wells, taking into account the readings of the IRGA gas meters with services and to expand the range of adjustment and optimization works at specific wells.

The telemetry system united gas flow monitoring and control nodes at oil fields, giving us the opportunity to manage oil production process from another city. It also combined several high dynamic range ultrasonic flowmeters in the network, providing gas consumption map of the region. At the same time, we managed to test our new flowmeters in real operating conditions. This telemetry system also helped us to remotely verify domestic gas flowmeters by our new ultrasonic mobile stand.

References

[1] Velichko M, Satler O, Krasovskaya L, Bronnikova M, Belyaeva I, Kostina I and Gladkikh Yu 2018 Calibration of Ultrasonic Flow Meter on Wi-Fi Network Using a Web Browser *J. Advanced Research in Dynamical and Control Systems*, **08-Special Issue** 1593-6

[2] Velichko M, Satler O, Krasovskaya L, Erina T, Belyaeva I and Gladkikh Yu 2017 Using Drone as WiFi Access Point During Infrared Thermography for Subsidiary Data Acquisition *J. Fundam. Appl. Sci.* **9(1S)** 1279-88

[3] Velichko M, Chernyavskikh S, Kostina I, Gladkikh Y, Krasovskaya L 2018 Improving educational process quality in the lessons of natural and mathematical cycle by means of STEM-training *Cypriot J. of Educational Sciences* **13(4)** 501-10

[4] Hamidullin V, Malakhanov R and Khamidoullina E 2001 Statics and Dynamics of Ultrasonic Flowmeters as Sensing Elements for Power Control Systems. *IEEE Int. Conf. on Control Applications, CCA '01* (Mexico: IEEE) pp 680-5

[5] Fraņa D, Ono Y and Jen C 2011 Contrapropagating Ultrasonic Flowmeter Using Clad Buffer Rods for High Temperature Measurements *J. Dynamic Systems, Measurement and Control, Transactions* **1** 011007

[6] Hu L, Qin L, Mao K, Chen W and Fu X 2016 Optimization of Neural Network by Genetic Algorithm for Flowrate Determination in Multipath Ultrasonic Gas Flowmeter *J. IEEE Sensors* **5** 1158-67

[7] Luca A, Marchiano R and Chassaing C 2016 Numerical Simulation of Transit-time Ultrasonic Flowmeters by a Direct Approach *J. IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control* **6(63)** 886-97

[8] Gryshanova I 2007 The Effect of Duct Cross-sectional Shapes on Metrological Performance of Ultrasonic Flowmeters *Proceedings of the 5th Joint ASME/JSME Fluids Eng. Summer Conf., FEDSM2007* (San Diego) pp 27-31

IOP Conf. Series: Materials Science and Engineering **791** (2020) 012060 doi:10.1088/1757-899X/791/1/012060

[9] Hamidullin V 1995 Dynamics of Ultrasonic Flowmeters *Proceedings of the IEEE Ultrasonics Symp.*(Washington) pp 1109-13

[10] Gerasimov S, Glushnev V and Serov N 2018 Analysis of Calibration and Verification Indirect Methods of Ultrasonic Flowmeters *Digest: 13th Int. Conf. on Advanced Technologies, Systems and Services in Telecommunications, TELSIKS2017* (Niš: University of Niš, MTT) pp 451-4

[11] Bates R, et al. 2013 Development of a Custom On-line Ultrasonic Vapour Analyzer/Flowmeter for the Atlas Inner Detector, with Application to Gaseous Tracking and Cherenkov Detectors *J. of Instrumentation* **1(8)** C01002

[12] Gershman E M, Kruglo D S, Fafurin V A, Borisov A M and Sabirzyanov A N 2017 Flow measurement of two-phase flow by ultrasonic flow meters. *J. Transactions Of Academenergo* **1** 30-41

[13] Kuranov K N and Sergeev S S 1996 Avtomatizaciya rascheta parametrov ul`trazvukovy`x rasxodomerov [Automated calculation of parameters of ultrasonic flowmeters] *Sozdanie Resursosberegayushhix Mashin i Texnologij* [*Creation of Resource-Saving Machines and Technologies*] (Mogilev: Belorussko-Rossijskij universitet) pp 99-112 [In Russian]

[14] Strelnikov E A and Eremin I Yu 2016 K voprosu o povy`shenii tochnosti ul`trazvukovy`x rasxodomerov [The issue of improving the accuracy of ultrasonic flowmeters] *Zakonodatel`naya i Prikladnaya Metrologiya* [*Legislative and applied Metrology*] **1** 140-5 [In Russian]

[15] Abzalilova E R and Galimullina E 2017 Umen`shenie vliyaniya vibracii na tochnost` izmereniya ul`trazvukovy`x rasxodomerov [Reducing the influence of vibration on the measurement accuracy of ultrasonic flowmeters] *Vestnik Nauki i Obrazovaniy* **1(25)** 33-5 [In Russian]

[16] Tyryshkin R A, Sabirzyanov A N and Fafurin V A 2016 Chislennoe modelirovanie korrektiruyushhego koe`fficienta ul`trazvukovy`x rasxodomerov [Numerical simulation of the correction coefficient of ultrasonic flowmeters] *Matematicheskie Metody` v Texnike i Texnologiyax, MMTT* [*Mathematical Methods in Technics and Technologies, MMTT*] vol 9(91) (Saratov: SGTU im Yu A Gagarina) pp 17-23 [In Russian]

[17] Biryukov E A 2018 Preobrazovateli ul`trazvukovy`x rasxodomerov [The transducers of ultrasonic flowmeters] *Tradicionnaya i Innovacionnaya Nauka: Istoriya, Sovremennoe Sostoyanie, Perspektivy`* (Ufa: Omega Sains) pp 10-2 [In Russian]