Autonomous Alternative Complex with Remote Data Collection

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***Abstract* — The northern areas have a strategic importance for the Russian Federation. Enormous energy resources are concentrated in the circumpolar region. The successful development of the Arctic region requires high quality telecommunications systems. The power supply for these communication devices is an acute issue that needs to be solved in the remote areas of the Arctic. Satellite communication is available up to a latitude of 80° North. As a rule, the supply of satellite equipment needs diesel generators. In this paper, we propose the use of hybrid power energy sources, such as solar panels and wind turbines. Remote monitoring of such system makes it possible to understand the running processes, while generating electricity with the help of alternative sources of power. On the grounds of the analysis of available battery charge controllers from solar panels and wind turbines, the remote acquisition system was developed and tested in the Arctic. The system is based on a single-board computer RaspberryPI.**

Keywords-Alternative Energy; Remote Data Collection; Wind Turbine; Solar Panel.

I. INTRODUCTION

The northern territory plays a significant role in the economy of the Russian Federation. Currently, the Russian Federation has as priority the development of information and telecommunication systems. The Arctic has enormous reserves of important mineral resources, especially oil and gas, which are strategically necessary for the dynamic development of the Russian economy, the provision of the country safety in mineral resources and to protect geopolitical interests.

Within the mainland of the Arctic zone, there are a number of major oil and gas provinces (PNC) and deposits. Considering the initial recoverable resources in the Yamal-Nenets Autonomous District, the largest oil districts (which have totally over 100 million tons) are: the Timan-Pechersk one, with initial total recoverable hydrocarbon resources of 6 billion tons in fuel equivalent (the fourth place in Russia), Russian province, Novo Portovsoe, Sutorminskoye, North Komsomolskoe Tarasovskoe, Kharampurskoye oil deposits. More than 90% of the gas deposits in the district are unique and large - Urengoiskoye, Yamburgskoye, Bovanenkovskoye, Zapolyarnoe, Kharasaveyskoye, South Tambey with their reserves from 1 to 10.6 trillion m [1] (Figure 1).

The initial aggregate hydrocarbon resources of the Arctic continental shelf make about 100 billion tons of fuel equivalent, 80% of which is gas. The main hydrocarbon resources (approximately 70%) are concentrated in the Barents, Pechora and Kara Seas. The unique and large Shtokman Prirazlomnoe, Leningrad, Rusakovskaja hydrocarbon deposits are located here. The commercial development of fuel and energy of the Arctic shelf is going to stabilize the dynamics of oil and gas production since it compensates possible recession of production activity in the continental deposits in the years 2015 - 2030. But this is possible only if material, scientific and technical foundation for the offshore oil and gas deposits development is provided.

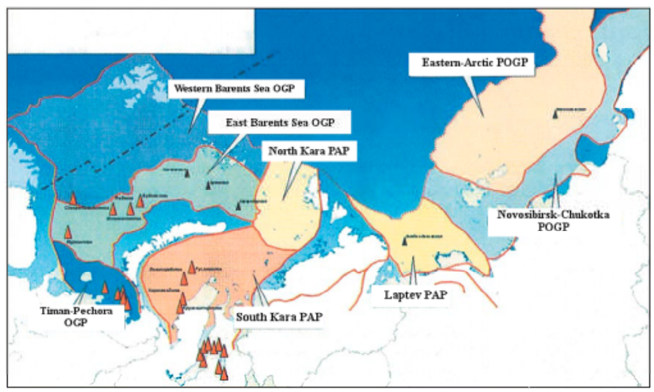

Figure 1. Oil and gas provinces in the Arctic region of the Russian Federation.

The marine transportation system, especially the Northern Sea Route, takes a special place in the transport sector of the Arctic region. The shortest routes between markets of northwestern Europe and Asian countries pass through the Arctic zone. The increased transport activity in the global economy for the development of transcontinental transportation, the increase of oil and gas production on the continental shelf of the Arctic, the improvement of the internal and external transport needs, have all led to the growth of the Northern Sea Route role and importance. When using the Northern Sea Route instead of operating the routes through the Suez and Panama Canals, the route from Rotterdam to the port of Yokohama is reduced by 34%, to the port of Shanghai by 23%, and to the port of Vancouver by 22% [2].

The vast distances and high-latitude location of the Arctic make it difficult to build communication systems in this area. The organization of a telecommunication infrastructure in the Arctic region meets both technical and organizational difficulties. Having analyzed foreign publications about projects focused on providing satellite communications in the Arctic region, it can be concluded that many countries are looking for the best way to implement systems for satellite communications management in the Arctic (Figure 2).

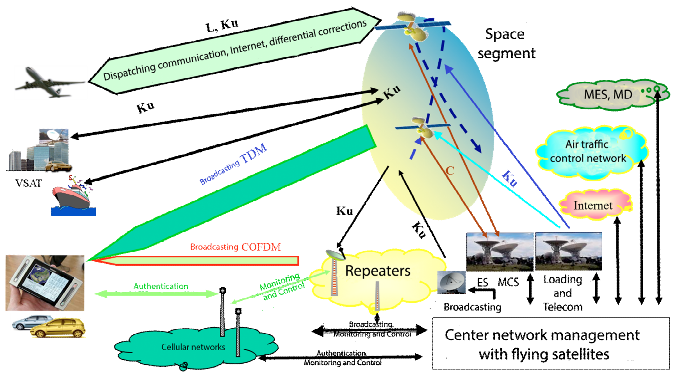

Figure 2. Architecture of the Arctic Communications System.

The number of scientific and technical papers and articles on this subject in international journals and conferences has increased by several times over recent years. It shows this topic became urgent. However, a single technical solution does not exist. The majority of projects relate to the creation of the space segment based on satellite in elliptical orbits, but, in some publications, the authors rightly point out strong influence of the Earth's radiation belts, which can cause the reduction of the satellites viability [3]. The "Tundra" orbit type is offered as an alternative [3]. We should note that, today, the circumpolar region has only one Iridium system working adequately, but, for personal communications, this system has many limitations in bandwidth [4].

The other systems, such as “Globalstar”, and especially Inmarsat, are available only up to a latitude of about 70° North [4]. Any other geostationary systems have the same limitation, although there are some examples of their usage up to 80th latitude (Table. I presents estimates of fading in the radio link). The low-orbit systems, like “Orbcomm” [5] or the Russian system "Gonets" [6], which is planned to be deployed, actually are not communication systems, but data transmission systems working like "email".

TABLE I. FADING OF THE RADIO LINK FOR THE CLIMATE ZONE IN THE WESTERN PART OF THE BARENTS SEA

Frequency, GHz	Elevation angle of 2-3°, dB		Elevation angle of 5°, dB	
	Precipitation	Without precipitation	Precipitation	Without precipitation
30	26	22	15	12
14	8	6,4	4,7	3,4
6	2	2	1	1

The Russian market of satellite communications is based on the resources of the orbital groups named FSUE (Federal State Unitary Enterprise) "Satellite Communications" and Public corporation "Gazprom Space Systems". The first group is represented by 11 communication satellites; the second one is represented by the two satellites "Yamal". The stable connection area with geostationary satellites (elevation angle of 5 degrees) is shown in Figure 3. The main types of traffic are: spreading television and broadcast programs according to broadcast zones; telephone lines and data transmission; data exchange in enterprise and dedicated networks; direct television and audio broadcasting; mobile and fixed government bond (totally about 300 transponders).

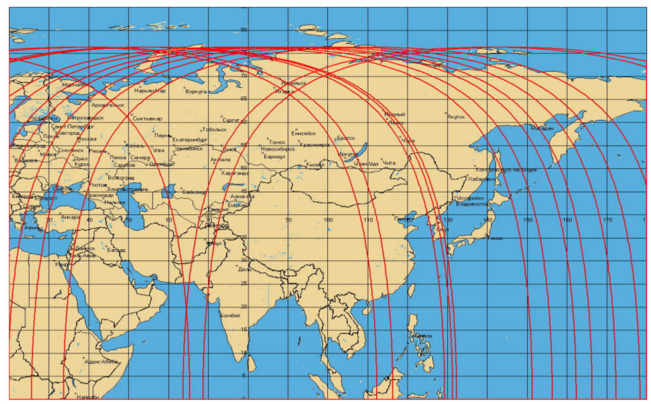

Figure 3. Stable connection area with the geostationary spacecraft (elevation angle of 5 degrees.)

Satellite communication devices are low-power devices. According to research, the maximum possible power consumption is limited by 900 VA. Currently, for the power supply of satellite communication devices in the Arctic, diesel generators are commonly used; they consume quite a lot of fuel and pollute the environment.

It was decided that the installation of the current power supply of satellite communications be established at Cape Desire of Novaya Zemlya archipelago (76°51' North latitude, 68°33' East longitude). There was no possibility to leave a researcher at the installation place, so a remote acquisition system was needed.

Data acquisition systems are essential to estimate the potential of renewable energy sources. For instance, a large quantity of data from different years is necessary to estimate scenarios using renewable energy sources. These aspects have an importance, mainly for developing countries, where decentralized power plants based on renewable sources are in some cases the best option for supplying electricity to rural areas. Nevertheless, the cost of commercial data acquisition systems is still a barrier for a greater dissemination of such systems in developing countries [3]. A local web server (on board) is constrained by lower memory limitations for storage of large amounts of data. In addition, satellite channels in the Arctic have very low bandwidth, so usage of this method is not possible.

Hence, remote operators of renewable energy plants connected to that local web server can view only limited data [7]. The applied data is usually organized in text files, which is inefficient. Hence, the development of an automated database is indispensable [7]. The monitoring system consists of a microcontroller-based unit to acquire interest signals, while the collected data is transmitted to a database server by a Ground Station Module (GSM) modem. The GSM standard extends the effectiveness of the system independently wherever the plants are placed, even far from the electrical distribution network and from the traditional and wired telecommunication systems. Due to the low cost and diffusion of the GSM devices, the transmission system is fairly cheap and it is expected to become even cheaper [8]. The collected data is further processed, stored on the disk and displayed on the web page using the PHP language (Hypertext Preprocessor). This method has the advantage of a rapid data acquisition system development and provides an easy-to-use graphical environment that permits system operators to process the collected data easily. The maintenance operator presence in a decentralized renewable energy plant should be as low as possible, considering the moderate value of the energy produced [8]. This way, the purpose of the present paper is to allow such plants to be remotely monitored and controlled by a remote operator.

II. ARCTIC EXPEDITION

In recent years, the study of the northern and Arctic areas has been growing very fast. The number of weather stations, scientific bases, oil and other extractive companies building settlements around the deposits is increasing. Any living infrastructure requires energy, and the increased consumption of petroleum products is not economically feasible. The wind and solar energy application technologies have already been considered to be used successfully for a long time in the southern areas. The northern areas impose serious constrains on the use of such systems, especially in the Arctic region.

Our team began to study the possibility of introducing alternative energy systems on scientific, weather, oil and other stations in the Arctic region. During the laboratory tests for the project, various "green" energy systems were installed in Novaya Zemlya archipelago and in the Zhizhgin Island, which is situated in the White Sea. As these systems have low efficiency and are not stable enough to work, the construction of full-power stations for livelihoods is a rather expensive and unprofitable task. Therefore, in our studies, all the systems were created to provide people with a permanent connection to the mainland. Due to the temporary need of communication with the mainland and because the amount of energy consumed by the communication systems does not exceed 200 watts at peak load, the use of such systems is considered appropriate.

The project targets is to:

- determine the most appropriate hardware configuration for the conditions of the Far North;
- provide a stable working condition of the communication system and configure the system so that it has maximum autonomy.

At this stage, this is considered a research project. Therefore, one of the priorities is to obtain the maximum possible amount of information about how the constructed systems work. Thus, it is necessary to design a hardware and software system for the collection, processing and presentation of data on the alternative energy system functioning in the Far North.

III. DESCRIPTION OF THE GENERAL SCHEME

Our team has been conducting studies on this subject for two years. The initial step was to install the first test alternative energy complex in Novaya Zemlya archipelago. During the first laboratory tests, we decided to use the interfaces provided by the equipment suppliers without any modification. The system was installed near the research station that had a satellite communication channel. The network had a direct connection to the controller of the solar panels and the data was obtained through the server inquiry. Not only solar panels, but also a wind turbine of horizontal type was delivered to the archipelago. Unfortunately, we were unable to read the data from the wind turbine controller. According to the results of the first laboratory tests, the following conclusions can be drawn:

- it was determined that the use of horizontal type wind turbines is impractical in the Far North due to the gusty wind, quickly changing the direction of movement;
- the data collection should be performed by the system and not by the server, since, in the first case, the service traffic required for communications protocol demands many expenses for the satellite channel;
- the data obtained using standard controllers was found to be insufficient; it requires additional sensors installation.

Based on the above conclusions, we assembled the second installation. In the complex, we decided to use wind turbines of vertical type. However, this controller did not have the ability to be connected directly to the network. It was necessary to use the digital output RS232 to receive telemetry data from the controller. Based on the previous experience, we decided that the data will be collected not by the server only, but by the complex itself. This method helped to solve several problems at once. Firstly, we accessed the data from several devices. Secondly, there was a possibility to obtain and collect data even in the absence of the Internet connection with the system. Thirdly, there were additional opportunities to collect and send data, as well as to control the whole system.

SBC Raspberry Pi [9] was chosen as a device for data collection. The main advantages for us were, firstly, its low energy consumption, which helped to save the system efficiency in the conditions of very strong battery discharge, and, secondly, it has a complete operating system at a sufficiently low cost and small size of the device. All these factors helped to reduce the development time and improve the whole system reliability.

After the second installation was tested, the new technical requirements to both the system and the software were determined. In the Arctic region, the quality of satellite communication is extremely unstable because of various reasons. Therefore, we faced the problem of data safety during the process of transmission. While operating, the data was revealed to be obtained after a long delay and was incomplete. For further studies, it was necessary to increase the reliability of the data transmission through the unstable Internet connection.

According to the results of the second laboratory test, the remote acquisition system was completed and implemented into the third complex of "green" energy. We finalized the technological infrastructure of the complex. As the equipment from other manufacturers was used, the number of devices requiring data collection was increased. The final system consists of the two wind turbines [11] and the four solar panels [12] that must be operated by the two hybrid charge controllers [13]. Each controller is connected to one wind generator and two solar panels. The system also includes four batteries [14] and an inverter [15] converting voltage from 12 to 220 V and managing energy flows in the system. Thus, the operation of the complex can be divided into three stages:

- Conversion of solar and wind energy into electrical energy;
- Buffering the electrical energy;
- Consumption of the accumulated energy.

The individual devices are responsible for each stage of the system. Therefore, all devices that compose the complex can be divided into three groups.

The first group of the devices, which are responsible for the conversion of “green” energy into electrical energy, includes charge controllers. The devices of this group provide data on direct work of the energy sources and display battery charge during their charging. In terms of the data obtained from these devices, we can, on one hand, receive information about the performance of energy conversion devices as a complex, and, on the other hand, watch each of them separately. The second group is represented by the storage batteries of various power that are able to accumulate electric charge. The third group consists of the inverters and provides information about energy consumption and the state of the battery during the process of their discharge. Thus, we have so far covered the stages of energy generation and energy consumption. The stage of energy buffering is the only one left uncovered. A device to control batteries was developed based on the microcontroller ATMega8 [16]. Using this, we were able to control the voltage of each battery in the system. Monitoring of the current flowing through each section of the circuit became possible by connecting current sensors to each battery. Thus, we could follow the status of each battery separately to react to possible failures in time. The circuit system described above is shown in Figure 4.

While designing the monitoring system, we had to solve some problems. In places where it was planned to install such systems to communicate with the "main land", the satellite channel is mostly used. The GSM channel is available in exceptional situations. However, both of them are quite expensive, so we needed to minimize the amount of data traffic, but not at the expense of the volume of data transmitted. In addition, it should be noted that the satellite channel is sufficiently sensitive to weather conditions and so disconnections can take place. Therefore, it was essential to provide a guarantee of either data delivery or delayed delivery.

We chose the JSON document format [17] as an internal data format for data storage and its transmitting to the mainland. This data format is very suitable for computer processing and, unlike XML, is compact enough. The binary data formats were rejected as the JSON documents appeared to be more compact than the binary ones [17].

As mentioned above, all the data from the system of the alternative energy is read using the single-board computer RaspberryPI. It takes readings from all the devices connected to it twice a minute, forming a "snapshot" of the entire system at any given moment in time. The collected data is added to the daily log, which is stored in a separate file. Originally, we considered the asynchronous data collection from each device with a separate entry in the log because each parameter has its own validity interval. The weak point of this method is the difficulty to carry out correlation of the readings, since we still have to register all the data at one time.

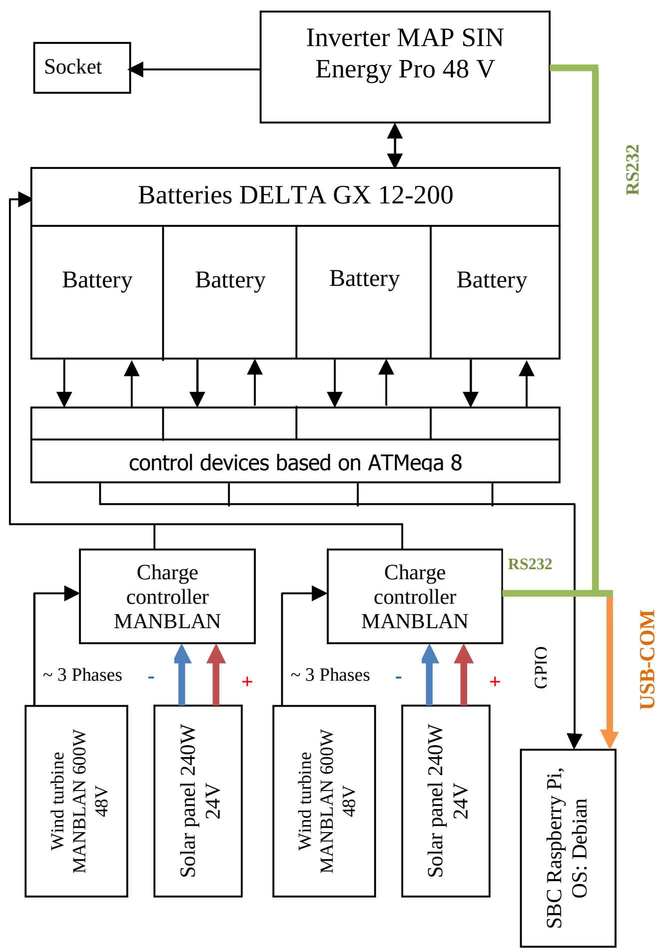

Figure 4. System circuit.

The problem of the unstable channel was solved by using the synchronization system Rsync [18] through the SSH connection to the server. The embedded Rsync data compression algorithms significantly reduced the amount of the data traffic. The streaming compression of SSH connection did not give such results. Rsync also allowed us to solve the problem of disconnection as it has the algorithms of the file difference transmission.

Once the data is delivered to the server, the documents are sorted out and the sorted data is carried over into the single database. PostgreSQL [19] was decided to be the database due to its ability to use multiple programming languages in store procedures [19]. Based on the incoming data, the database automatically counts and updates daily, hourly and monthly reports for each installation point. This data transmission is presented in Figure 5.

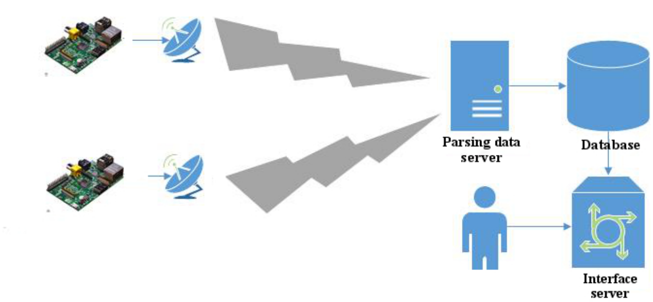

Figure 5. Data traffic pattern.

IV. RESULTS

This project resulted in designing the hardware and software complex that allows remote monitoring of the alternative energy systems through the data collection from the maximum number of sources. Such sources can include not only ready devices such as charge controllers but also a variety of additional current and voltage sensors. The configurability of such systems explains the integration of the scaling feature of several devices and sensors that need monitoring. If necessary, the system supports connection to some additional devices, for example, a portable weather station. Our laboratory tests were run in the vicinity of the meteorological stations, so we did not need such data. However, if these systems are required to be installed in remote areas, the weather information is vital to control the entire system.

Data transmission takes a special place in our system. We took its design seriously. The foreground task was to ensure a reliable transmission of the telemetry data and its safety. According to the research results, this task was accomplished.

We generated a web-interface to control the system operation. This interface allows the available data to be viewed in a convenient form from each system designed by our team. Currently, we can view the archival data obtained from the solar panels located at Novaya Zemlya as well as the data from the island Zhizhgin. The data received from our recent tests is preparing to be published. The web-based interface was originally built on the PHP framework Yii [20]. However, for technical reasons, it was moved to a python framework Django [21]. The main reason for changing the framework was rather small amount of code if case of using Django. One more reason was the number of programmers in our team who know syntax of python so we could support this product better and faster. The main function of data-viewing was realized. We plan to increase the functionality of the application to query the historical data and to compare it in different variants. The Yii framework screenshot is presented in Figure 6.

Figure 6. Web-interface, created on the Yii Framework.

In general, on the grounds of the research results, it may be concluded that the use of alternative energy systems in the Arctic region is highly promising. However, the use of such systems in the northern regions requires constant monitoring and studying the effect of the weather conditions. These scientific studies target long term testing. Presently, such systems are rarely used in the North. We need to determine how long they are able to work to be successfully and efficiently used.

V. CONCLUSION AND FUTURE WORK

After tests, we can conclude that, in the conditions of the northern latitudes, the use of horizontal wind turbines is not suitable because of their instability to gusty winds. The vertical wind generators show a better performance, but still require some modifications to strengthen their structure. During the summer, the wind turbines produce power stably. However, their power depends strongly on the wind direction and strength variability.

In the future, we plan to use horizontal wind turbines along with vertical ones for a more stable work. Our last research in data acquisition and representation shows better results in case of using Zabbix as monitoring system [22]. While using this system, we had interesting results. But we also experienced some problems in its performance and user interface. In the future, we are planning to solve these problems and use the system with our own interfaces.

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