Increasing the Efficiency of District Heating, Case Study

Andrei Valentin Baicu* and Sorin Voican

***Abstract*—Increasing the efficiency of district heating systems, maximizing the integration of renewable sources and the excess heat required from industry area by area in the context of decarbonization and reduction of fossil fuels at European level. In this context, district heating networks tend to become more and more complex, incorporating multiple sources of heat production and prosumers. They interact with other energy sectors, gas, electricity or urban cooling networks.**

Given the complexity that appears in this situation, digitization becomes a necessary condition for achieving the objectives in network operation. At the production level, without digitization in the form of intelligent control, the maximization of sustainable sources cannot be achieved. Sustainable energy sources, being influenced by environmental factors, are unpredictable and difficult to control. This aspect determines the use of some types of heat network control.

Digital technologies are expected to transform the entire energy system into a smarter, more efficient and sustainable one that can integrate various types of renewable energy into the system. Achieving these desired is expected from IoT, automation, Artificial Intelligence and Big Data.

***Index Terms*—Digital solutions for district heating**

I. Introduction

The present paper makes a case study of a heating network in Romania, identifying the digital solutions that lead to the achievement of the above objectives. The district heating of Bucharest - SACET, gives the case study. This is largest heating system network in Romania and represent 43% of the national market. This network of thermal energy supply system, provides 72% of the thermal energy needs of the Municipality of Bucharest. 95% of consumers are domestic (aprox.500000 apartments), the rest being social and industrial (public institutions and economic agents).

SACET has a unitary technological and functional assembly consisting of:

Thermal plants; electric heating plants; transport networks; distribution networks; thermal points; thermal stations; branches to the delimitation/separation points of the facilities; measurement, control and automation systems. The source of thermal energy production is represented by eight thermal power plants, one area thermal power plant and 49 neighborhood thermal power plants. The centralized food insurance transport thermal network with thermal energy from its production source and has a length of approximately 851.4 km. The secondary thermal network ensures the distribution of thermal energy for heating and hot water to consumers and has a length of 2763 km.

The main technical characteristics of the infrastructure of the public thermal energy supply service are presented in Table I.

TABLE I. Main Technical Characteristics of Public Thermal Energy Supply Service

Heating agent transport network		Km pipeline	851,84
Heating agent distribution network	Distribuiton	Km pipeline	2.763
	Thermal plants	Km pipeline	198,34
Thermal distribution points	Urban	Pcs.	591
	Subsidies	Pcs.	56
Centralized stations	Urban	Pcs.	14
	Subsidies	Pcs.	4
Thermal modules	Urban	Pcs.	264
	Subsidies	Pcs.	44
District heating plants		Pcs.	45
Thermal power plant		Pcs.	1

The promotion of renewable energy sources is an important objective for Romania at the level of 2，030, in the context of the transition to green, clean energy. Romania, considering its particularities, has set its objective to achieve a share of energy from renewable sources in the final gross energy consumption of 30.7% compared to the share of 24.4% in 2020. Forecasting the transformation of the European Union into a modern, competitive and efficient economy from the point of view of the use of resources, the European Green Deal [1] establishes the following objectives:

1) Reducing greenhouse gas emissions by at least 40% by 2030, compared to 1990
2) Increasing renewable energy consumption by 32% until 2030;
3) Improving energy efficiency by 32.5% until 2030;
4) Interconnection of the electricity market at a level of 15% by 2030.

All this transformation process needs financial support. The funds allocated to Romania through the Modernization Fund [2] aim to finance investments in the following priority sectors:

- renewable energy sources -including electricity sector, heating and cooling sector;
- energy storage -including research, development, innovation activities;
- energy infrastructure –including electricity transport and distribution networks, heating networks;
- high efficiency cogeneration
- new electricity capacity to replace coal and balance the network;
- nuclear energy –including research, innovation and development;
- production and use of green hydrogen;

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- energy efficiency in industrial facilities
- production of biofuels;

There are some preliminary steps in increasing efficiency and achieving the European goals: modernization of the district heating network, another is the introduction of renewable energies as sources in the network and the last one we are referring to in this article, is digitalization of district heating.

The digitization of the heating network involves IoT, Big Data, AI, and Digital Twin.

II. Internet of Things

Specialized literature provides us enough information about possibility of using Internet of Things in the district heating system [3]. Modernization of thermal energy measurement systems, implementation of an IT system for remote reading of thermal energy measurement means and modernization/replacement of fittings, the calming zone related to each metering loop and differential pressure regulators, necessary in hydraulic balancing of the heating installation.

This involves:

1) Modernization of the thermal energy measurement systems and related fittings, together with the quieting areas, with the equipment of the connections to the consumers with balancing loops to optimize the flow and pressure parameters;
2) Equipping thermal energy meters for remote data transmission; collecting the data transmitted by the meters and transporting them up to the central data server level;
3) Storage, interpretation, analysis, visualization, alarming and reporting of data collected from meters using a dedicated software platform.

The advanced monitoring of the technical indicators of the operation of the transmission and distribution networks will allow the optimization of the operation, but, above all, the most accurate dimensioning of the investment efforts aimed at reducing heat losses.

From the perspective of the demand for heating agent used in SACET Bucharest, it was considered an evolution of the demand for heating agent used calculated on the basis of the actual demand for heating agent in recent years based on data received from the operator of SACET.

TABLE II. Evolution of Demand for Heating Agent

Influencing factor	Percentage of change	Change	U.M.
Disconnection	–0,0226%	–654,05	Gcal/year
Reconnection& new customers	–0,1055%	3.053,81	Gcal/year
Global warming effect	–0,1301%	–3.766,70	Gcal/year
Thermal insulations measures effect	–0,4081%	–11.814,78	Gcal/year
Demand increase index in relation to real sales as a result of the impossibility of sustaining real demand	0,50%	14.475,51	Gcal/year
Total influence		**1.293,79**	**Gcal/year**

The data collection from the installed thermal energy meters will be done with the help of a fixed data collection network that uses the narrowband IoT (NB-IoT) communication protocol. Narrowband IoT protocol is a wireless internet of things protocol using low-power wide area network technology [4]. Why is that? The choice of the NB-IoT communication protocol is motivated by the requirements imposed by the application of data collection and transmission from the entire meter park of district heating operator:

- hourly data transmission frequency in the conditions where the thermal energy computer is powered from a battery
- relatively large telegram size (compared to other data transmission applications in the IoT sphere)
- the need to ensure the security of data transmission,
- the need to choose a data transmission protocol that is not affected by the high level of radio noise characteristic of the City of Bucharest.

Other communication protocols of the same class used for this type of applications (wMBus, LoRa, Sigfox, LTE-M etc.) meet only some of the required conditions: e.g., LoRa ensures low power consumption, but transmits small telegrams and communicates in the 868 MHz frequency band, a public frequency strongly affected by radio noise; Sigfox works in a similar way to LoRa; LTE-M ensures the transmission of large and very large telegrams, but with significantly higher energy consumption, etc.

Equipping energy meters for communication assumes that each thermal energy computer will have a wireless communication module installed that uses this communication protocol. Each thermal energy meter will transmit the collected data at least every hour, thus ensuring the needs of operator: to have access to consumption and status data in a timely manner, to ensure the ability of the company, to react in the shortest possible time to fix any problem signaled by the meter through functional and status alarms.

Each NB-IoT communication module installed in the thermal energy meters will have a SIM card installed that ensures enrolment and communication in the telecom operator's NB-IoT network that will ensure connectivity throughout the entire geographical area of SACET Bucharest.

The data will be transmitted by the meters, picked up by the NB-IoT network and transported to the operator data server, from where it will be picked up and processed in the Meter Data Management (MDM) software platform.

The general architecture of a fixed network data collection infrastructure on the NB-IoT protocol is shown in Fig. 1.

Expected results through the implementation of the project:

- Reduction of thermal energy losses in heat transport and distribution systems;
- Knowing as accurately as possible the quantities of thermal energy traded annually;
- Increasing operational efficiency
- Increasing customer satisfaction; - Fulfillment of the

objectives set for the year 2030 regarding climate and energy;

- Increasing energy security through the security of consumer supply and the reduction of thermal energy losses;
- Ensuring a sustainable development of district heating operator.;
- Improving the quality of public services provided;
- Energy efficiency.

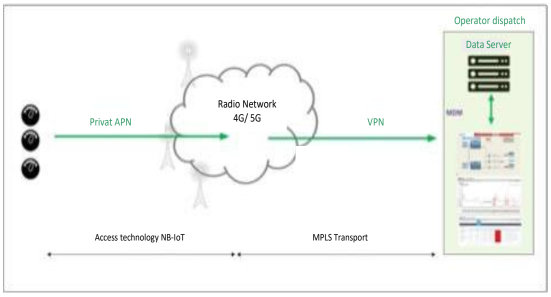

Fig. 1. General architecture of a fixed network data collection infrastructure on NB-IoT protocol

III. Automation

At the national level, law elaborates policies in the field of energy efficiency no. 121/2014[5]. Among the objectives established by this law, we mention the introduction of high energy efficiency technologies, modern measurement and control systems, as well as energy management systems, for monitoring, continuous assessment of energy efficiency and forecasting energy consumption.

According to the above, the district heating of Bucharest must align with the objectives that encourage energy efficiency, which aim to implement new automation systems for thermal points (urban and endowments) and a new system of supervision and operative management (SCADA) for thermal points (urban, industrial and endowments), modules, nodes and thermal plants, as well as for the zonal dispatchers and the general dispatcher under the administration of the district heating operator.

The automation system must perform the following functions:

1) Changing the parameters of the thermal agent for heating and domestic hot water according to the adjustment curve for heating and the reference values for hot water;
2) Permanent assurance of the flow rate of the thermal agent and the reference values for hot water;
3) Permanent provision of hot water pressure to consumers according to the values established by the project;
4) Permanent assurance of the pressure of the thermal agent for heating in the installations of the secondary thermal network related to the thermal points and modules;
5) The possibility of interrupting the circulation of the thermal agent for heating in the situation where it does not present the parameters established by the adjustment curve.

The dispatcher system and SCADA operative management must perform the following functions necessary for efficient exploitation:

1) Remote control of the main execution elements (adjustment valves, electric pumps, expansion modules, electric valves in thermal nodes, etc.);
2) Remote modification of heating adjustment curves and hot water reference values;
3) Remote closing/opening of electric pumps;
4) d) Remote closing/opening of the solenoid valves in the thermal nodes;
5) Continuous monitoring in the event of a problem in the operation of thermal points or modules by triggering warning alarms, for the purpose of rapid intervention to remedy damages and connect operational deficiencies;
6) Recording and permanent monitoring of technological parameters (pressure, temperature, flow of thermal agent), necessary to replace reports of operational analyses, balance sheets, etc.;
7) Generating production reports in order to:

- Establishing the losses on the primary and secondary circuits (volume and energy), where there are measurement systems;
- Analyzing the operating parameters of thermal points or modules;
- Analysis of electricity consumption;

8) Correlation with the other technological objectives in the heating system (transportation system, metering system, etc.) - in addition, at the level of the data platform, an Enterprise Service Bus (ESB)-type integration and data exchange module is provided that eliminates the need to impose certain communication channels for the exchange of data that would lead to limiting the competition of bidders in the following contracting phases;

“An ESB, or enterprise service bus, is an architectural model through which a centralized software component performs integrations between applications. It performs data model transformations, handles connectivity, performs message routing, converts communication protocols, and possibly handles the composition of multiple requests. ESB can make these integrations and transformations available as a service interface for reuse by new applications” as IBM company [6] defines.

To accomplish the above objectives, these call for basic SCADA functions as well as connecting multiple software applications. Connecting different software applications and systems can be achieved through three basic concepts. It should be noted that the integration of a software is not only about the exchange of data, the integration means the exchange of data and a common definition for the functions, what must be done with the exchanged data.

The first concept can be achieved by requesting a solution from a supplier that meets all requirements. This sometimes leads to highly efficient solutions with a high integration uptime, but at a high cost.

The second concept, the most frequently used, resides in the construction of specific interfaces between the applications to be integrated. So, taking an example with 4 integration systems, as in Fig. 1, to take care of the requirement that each application communicates with the others, it is necessary to create 6 interfaces.

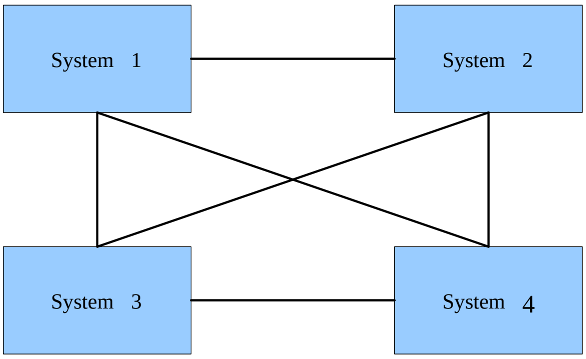

Fig. 2. How to connect type 2 software applications.

The third concept is to use third-party software to manage the exchange of data and messages between different software applications, as shown in Fig. 2.

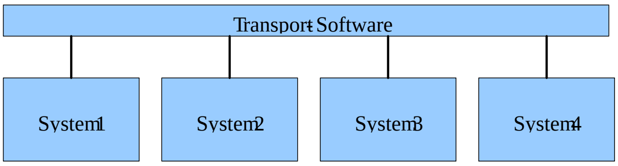

Fig. 3. How to connect type 3 software applications.

In case of an update for one of the systems, the logical components and configurations are stored in the transport software, so only the adapter needs to be examined.

The recommendation for the interconnection of the applications required by the network operator is to use the architecture described in the third integration concept as the basic technology for the integration of general IT, namely to communicate with the controlled applications via a secure VPN tunnel.

Modern computer systems intended for the operative management of energy installations are based on operational functions, such as those of the SCADA type.

The name of the functions and their content are generally standardized worldwide and the related software is commercially available in the competitive market.

In the following, detailed SCADA functions will be presented, specific to computer systems intended for operational management by dispatcher of thermal energy transport and distribution networks.

An IT system equipped with SCADA functions achieves:

1) Data collection, reception and exchange;
2) Data validation, processing, display, archiving;
3) Development and execution of remote controls in the facilities, which allows the operator (dispatcher) to supervise the operation of the facilities in real time, decide the actions to be taken and intervene remotely if he considers it necessary (operational commands or remote controls). Expected results through the implementation of the project:

- reduction of thermal energy losses in heat transport and distribution
- improving the quality of services provided
- increasing operational efficiency

increasing customer satisfaction

IV. Big Data and Artificial Intelligence

For district heating, data has not been a focal point until recently, but with the advent of IoT and non-intrusive measurement technologies, access to data has become technically easy for both the operator and that of the consumer. Energy efficiency improvements are heavily influenced by optimization capability, which depends on both dynamic and static data and system models.

The large amount of information requires storage and information management solutions. This problem can be solved with some investments by internal departments of the district heating operator of Bucharest. The field of District Heating has seen a growing interest in applications of intelligent techniques with the purpose of reducing heat loss and growing the efficiency and different methodologies are proposed [7].

Based on the collected information, it is possible to forecast network maintenance work, establish the heating strategy and other predictive operations. The city's heating strategy is necessary in order to implement new sources of renewable energy and find solutions for heat deficit areas.

V. Digital Twin

Digital Twin is a digital representation of the heating network that combines geographic, weather and sensor data with AI-enhanced physical models. This involves the use of GIS. In this representation, heat sources, hydraulics and user data are integrated and used to optimize and predict the behavior of the heating system. Considering its expansion as well as the age of the component elements, the interventions in this system are different compared to those in other European cities. In order to respond to modernization needs, the intervention must be done in successive steps: first of all, the modernization and energy efficiency of the current centralized system must be done, and in the next phase, the implementation of solutions leading to energy neutrality and the transformation of the city of Bucharest - the city located under the influence of the district heating operator- in a Smart city. By creating the simulation system -digital twin- of the energy system and testing it in the district heating network, both the management of thermal energy supply and network maintenance interventions will be improved. The platform can provide modeling, management, citizen interaction, self-optimization, decision support/scenario analysis functions for all situations encountered. The simulation of various processes gives valuable information about how the network can behave in the situation of the addition of new sources of renewable energy. In this way, scenarios can be made regarding the introduction of water-to-water heat pumps or geothermal pumps on the lakes in the north of Bucharest, they can model the introduction of cogeneration or trigeneration units or photovoltaic panels to reduce electricity consumption from the grid.

VI. Conclusion

A wider implementation of information and communication technologies give possibility for a better operating of the system using real time measurement data. Using digital processes into district heating system give possibility of business process to be improved. Digital technologies will make the whole energy system smarter, more efficient and reliable and will give chance of renewable energy to be integrated. Of course, it is required the support of European funds, Romanian Government and local institutions for such a big investment and it will be a gradual process. This process can be staged and must be coordinated so that the departments involved have good communication between them and can find the best implementation solutions. A project implementation unit is a necessity considering the complexity of the project. This unit must connect the financial, investment, operational and IT departments. At the same thing, considering that the district heating network operator is subordinate to the Bucharest City Hall, the approval of the local Council is also needed when we talk about investments. The results lead to a better operation of the network and represent an important step in the transformation of Bucharest into a smart city.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

A. Baicu proposed the theme of article and suggested the parts of it. Both authors, A Baicu and S. Voican contributed to the different parts of the paper and all authors had approved the final version.

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