Non-Conventional Renewable Energy Potential for Improving Electricity Availability for the Residential Area of the Future

1st Cristian-Dragos Dumitru
Electrical Engineering and Information Technology Dept.
G.E. Palade UMPhST of Targu Mures
Targu Mures, Romania
https://orcid.org/0000-0001-5619-8982

2nd Adrian Gligor
Electrical Engineering and Information Technology Dept.
G.E. Palade UMPhST of Targu Mures
Targu Mures, Romania
City, Country
https://orcid.org/0000-0002-8724-4272

3rd Daniel-Stanciu Dragomir
Electrical Engineering and Information Technology Dept.
G.E. Palade UMPhST of Targu Mures
Targu Mures, Romania
https://orcid.org/0000-0001-5192-0999

4th Ilie Vlasa
Distributie Energie Electrica Romania Mures Branch
Distributie Energie Electrica Romania S.A.
Cluj-Napoca, Romania
https://orcid.org/0000-0002-8006-683X

***Abstract*—The EU and national regulations regarding carbon emissions reduction and renewable energies adoption focus on finding new ways on accelerating the development of new facilities installations and integration in existing grids but also on identifying new energy sources to cover the gaps left by the other existing solutions. This paper discusses about an alternative solution based primarily on local resources availability proposed mainly for high peak power demand coverage and, in the same time, for providing supplemental thermal energy for heating or cooling in civil applications. The main investigation tries to characterise the potential of solar-thermal energy, phase change materials, local materials with thermal storage capacity and low power electricity generation based on ORC cycle that operates on high efficiency refrigerants. The study concludes on opportunity and current challenges in designing, implementation and deployment of such solutions.**

***Index Terms*—renewable energy, solar thermal energy, thermal energy storage, phase change materials, thermal energy conversion.**

I. Introduction

Climate challenges, the reduction of conventional primary energy resources reserves and the significant increase in the purchasing electricity costs have created in recent years the premise of the transition to the large-scale adoption of systems based on renewable resources (RES). This trend has been accelerated by the increasing accessibility of RES-based systems from the perspective of implementation costs and government support, but also due to the increase in performance and the maturing of related technologies. However, the increase in the share of systems based on RES, due to the intermittency of the primary resource, cannot completely replace the traditional systems. Moreover, situations that generate operating problems of the current energy systems, materialized in the degradation of the service supply of electricity, increasing losses in transmission and distribution systems, or even user costs in certain circumstances appeared [1]. Under these conditions, the adoption of solutions that minimize the impact of these challenges is of real interest. Among the potential approaches we can identify the adoption of new systems based on alternative energy to the existing ones, the decrease of energy consumption by using more energy efficient consumers, by changing the usage behavior controlled by market mechanisms or intelligent technical systems, rolling out of new storage capacities and diversifying systems that contribute to stability maintenance and optimal operation of energy systems.

The previously mentioned changes in the current energy systems require a quick intervention to avoid jeopardizing the proper operation of these systems. Several major directions can be identified in this regard, such as directing research towards finding new solutions to compensate for current RES limitations, developing new technologies or using existing technologies that can capitalize unexploited local resources.

The first mentioned category raises problems from the point of view of costs and the reasonable time in which these new technologies can reach a suitable stage of maturity, but the second category is based on already known technologies, which only need to be adapted and increased in their efficiency to make them feasible for the intended purpose.

Some promising directions can be mentioned such as systems based on geothermal energy, based on biomass, energy recovery and conversion from technological processes, systems that use gravitational energy, systems that use thermal

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energy through heat pump technology, systems that use the potential energy of gases or the best-known approach based on hydrogen technology.

To obtain high powers by implementing these technologies, the costs can be significant, and in some cases, they raise the same problems as traditional systems, such as pumped storage systems that can affect the eco-systems in the region where they are implemented. However, an approach based on low-power local systems, due to lower costs, can represent a feasible option for the mentioned challenges, to be implemented at small or residential consumers . Moreover, they can bring horizontal benefits through the possibility of implementing and enforcing the roll-out based on incentives that can lead to the development of small and medium-sized businesses in this sector, employment and the use of local resources.

In this context, the present paper wants to present an unconventional solution for harnessing solar thermal energy to cover the demand in peak hours. The proposed solution uses the storage potential of local materials available on a large scale or of phase-change materials and the conversion into electrical energy using in the present case the Organic Rankine Cycle based on thermal agents operating at low temperatures.

The solution designed and analyzed in this work aims to demonstrate the feasibility of small-scale electricity production and the practical demonstrator implementation from components currently available on the market. A significant result of the presented research is represented by the application development embodied in a prototype of an experimental demonstrator that allows the undertaking of research in order to increase optimization and efficiency in operation.

The paper is structured as follows: in the next section is introduced the potential and oportunity to use ORC combined with renewable solar-thermal energy for electricity production, then in the third chapter the development of an experimental solution for small electricity power application is presented. In section IV the proposed implementation for the experimental solution is designed and analysed from the performance point of view.

II. Organic Rankine Cycle in Renewable Energy Solutions

Currently, we find many renewable sources based on thermal energy, such as those from geothermal systems, systems that utilize waste and biomass, heat recovery from different thermal processes or even those based on solar energy. A way of using these energy sources can be achieved, in the case of low temperatures, through the principle of conversion based on the Organic Rankine Cycle (ORC). Recently, more and more research into such devices is being undertaken, as the technology for converting low-temperature heat resources into electrical energy is attempted to be progressively adopted [6].

In August 2023, there were 1456 such projects implemented or being implemented worldwide. In an analysis made by Canadian engineer Thomas Tartière, in collaboration with Marco Astolfi, professor at the Politehnica of Milan, shows that in 2016 there was an installed capacity of 2749.1 MW, of which 76.5% geothermal, 10.7% Biomass, 8.5% heat recovery from gas turbines or heat engines, 4.2% heat recovery from other sources and 0.1% from solar thermal energy [3].

The map of the distribution of these applications shows that in the Balkans there are only a few ORC roll-out based solutions, for example, there are 8 in Romania, 4 in Bulgaria, and 11 in Greece, as can be seen in Fig. 1.

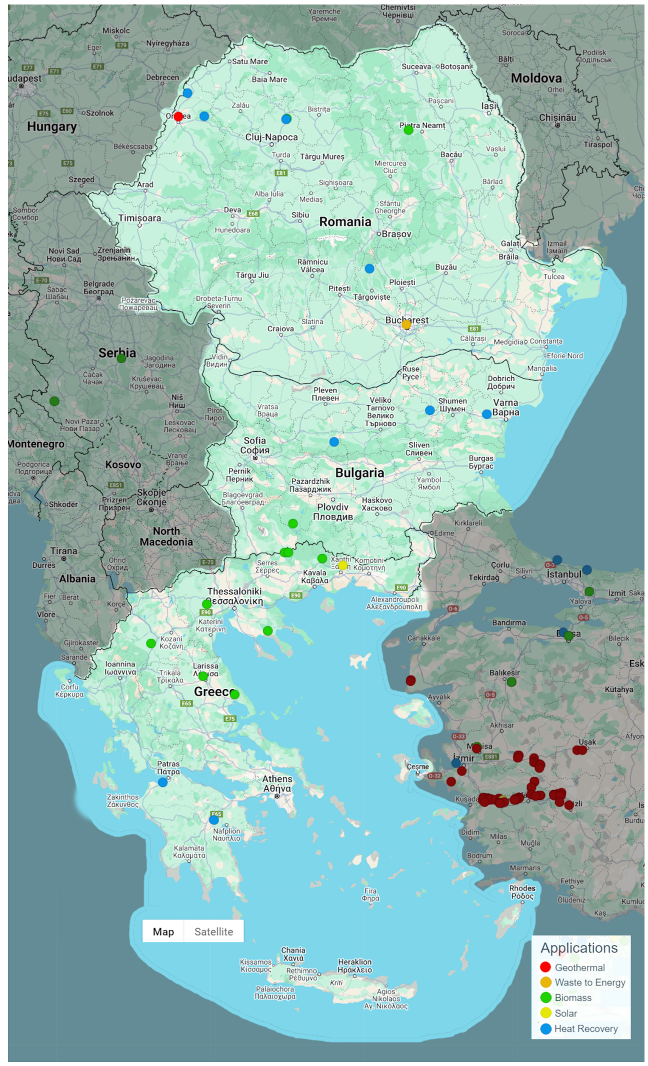

Fig. 1. ORC applications installed in the analized region [5].

This aspect represents an impetus and an opportunity for development in these regions, an aspect taken into account in the project Promoting Innovation Excellence in Transformation of Coal Regions to Climate-Neutral, Thriving Economies, HORIZON-WIDERA-2022-ACCESS-04-01 — Excellence Hubs, which brings together partners from the three mentioned regions and proposes the investigation of valorizing local resources combined with challenges and opportunities within the context and potential synergies with the Just Transition Fund to raise the level of innovation and financially support excellence in sectors related to sustainable energy.

The feasibility of covering this niche depends on the availability of primary resources, such as solar thermal energy and the desire of the economic environment to get involved in the development of businesses that capitalize on this opportunity.

As an example of solar energy potential usage, studies show that based on a average of yearly 800 to 2000 kWh/m^2 illustrated on direct radiation maps (see Fig. 2) good results can be obtained for valorisation of this type of resource.

Fig. 2. Direct solar radiation in the analyzed region [4].

III. Development of an Experimental Solution for Small Electricity Power Application

The proposed application is developed for the storage of the heat produced by solar thermal panels collectors and the usage of this storage thermal energy to produce usable heat and electricity. The diagram that illustrates the concept of solar thermal ORC conversion solution is presented in Fig. 3.

Solar energy is converted into heat which is stored at low temperature in a heat storage media such as water, sand or phase change materials (PCM) available locally.

The storage system consists of a heat exchanger, the material in which the storage is made, the tank and the insulating

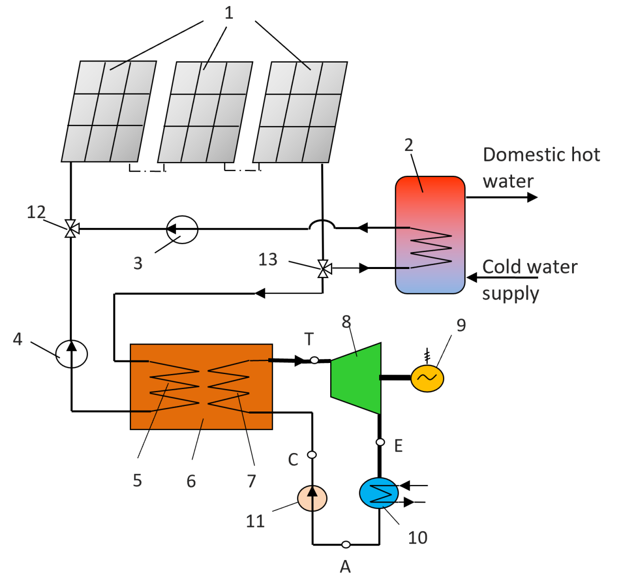

Fig. 3. Solar thermal ORC system concept: 1. solar panels; 2. hot water boiler; 3,4. water pumps for solar panels; 5. heat exchanger; 6. thermal accumulator; 7. organic fluid vaporizer; 8. turbine; 9. generator; 10. condenser; 11. organic fluid pump; 12, 13. three-way valve.

material of the tank that ensures the preservation of the stored thermal energy for a longer period.

An Organic Rankine Cycle based conversion system is used to convert stored heat into electricity mostly in periods when solar radiation is not or less available.

IV. ORCS System Implementation

Starting from the solar thermal ORC concept was designed an implementation scheme, shown in Fig. 4 and a potential assesment was performed using R134a thermal agent.

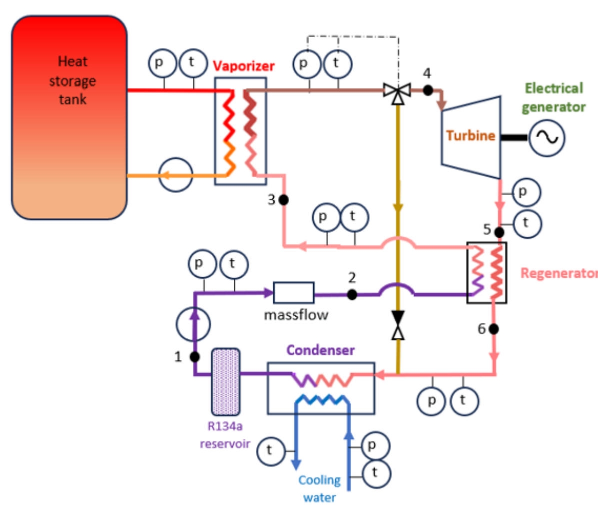

Fig. 4. Implementation of solar thermal ORC system: 1-2 Pump pressure increase; 2-3 Preheating; 3-4 Vaporization; 4-5 Expansion in the turbine; 5-6 Heat recovery at the regenerator (section 6 is on the saturation curve); 6-1 Condensation.

Fluid R134a evolves in the installation according to the thermodynamic cycle shown in Fig. 5, its thermodynamic parameters in the main points being presented in tab [y]. It can be seen that point E, which represents the actual exit of the steam from the turbine, is in the superheated steam area. Point T is located at a pressure of 13.179 bars and a temperature of 55 degrees Celsius. At the exit from the turbine we have a pressure of 6,007 bars and a temperature of 28 degrees Celsius. The cooling of the fluid from 28 degrees to 22 degrees will be done in the heat recuperator located immediately after the turbine.

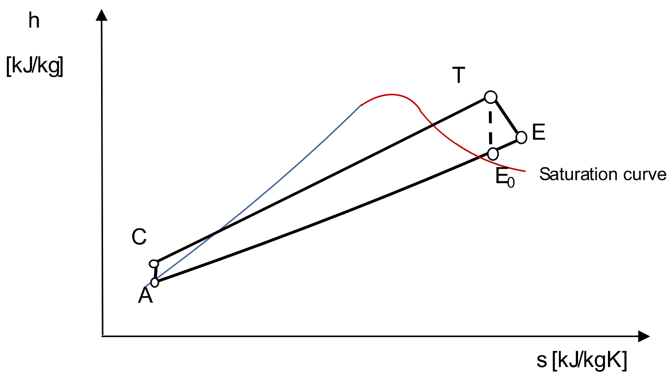

Fig. 5. Thermodynamic cycle for R134a thermal agent.

TABLE I
THERMODYNAMIC PARAMETERS IN THE MAIN CHARACTERISTIC POINTS OF THE R134A ORC CYCLE

Parameter	A	B & C	T	E0	E	R
p[bar]	6.077	13.179	13.179	6.077	6.077	6.077
t [ºC]	22.00	22.30	55.00	25.00	28.00	22.00
h [kJ/kg]	230.28	230.67	428.73	412.62	415.69	410.80
s [kJ/kg K]	1.104	1.1063	1.723	1.723	1.734	1.7173

Calculations were performed in Matlab software with the integrated suport of Coolpack library and reveals an 8.85% efficiency for selected temperature range and pressure adopted in installation.

V. Conclusions

To limit global warming, changes in energy systems are becoming inevitable and measures must be taken as quickly as possible. Photovoltaic and wind systems are becoming more widespread globally, but in addition to these, the use of low and medium temperature sources appears to be a reliable option for the success of meeting current climate goals, as the low energy conversion potential from sources such as energy geothermal, solar thermal systems, residual heat from biomass burning or other medium temperature environments is very high. Under these conditions, the Organic Rankine Cycle seems to be a technology that would be perfectly suited for the exploitation of these low or medium temperature energy sources.

The economic and environmental benefits, together with the reliability and versatility of such a technology, make it attractive for various applications.

One of the main problems is the high cost of implementing such systems, but considering that they are reliable and resistant systems over time, and the maintenance costs are quite low, it can be said that such an investment can considerably compensate for the high costs of implementation.

Even though on a small scale, the efficiency of these organic Rankine cycle power generation systems is relatively low, it may be sufficient for certain fields of activity. The more powerful these systems are, the more efficient and cost-effective they are.

In the future, it is expected that such systems will appear more and more, and the technical parameters of the cycles will improve with the appearance of new working fluids that will allow them to store larger amounts of heat.

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