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SMART ENERGY

SMART GRID DEVELOPMENT: MULTINATIONAL DEMO PROJECT ANALYSIS

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This paper analyses demand side management (DSM) projects and stakeholders' experience with the aim to develop, promote and adapt smart grid tehnologies in Latvia. The research aims at identifying possible system service posibilites, including demand response (DR) and determining the appropriate market design for such type of services to be implemented at the Baltic power system level, with the cooperation of distribution system operator (DSO) and transmission system operator (TSO). This paper is prepared as an extract from the global smart grid best practices, smart solutions and business models.

Keywords: *demand side management, demand response, electricity market*

1. INTRODUCTION

According to Energy Efficiency Directive 2012/27/EU and its Article 15.4, all EU member states are required to "ensure the removal of those incentives in transmission and distribution tariffs that are detrimental to the overall efficiency (including energy efficiency) of the generation, transmission, distribution and supply of electricity or those that might hamper participation of demand response, in balancing markets and ancillary services procurement", whereas Art. 15.8 of the Directive states that "member states shall ensure that national regulatory authorities encourage demand side resources, such as demand response, to participate alongside supply in wholesale and retail markets." In addition, the European Commission "Winter Package" highlights that future electricity grid will integrate more renewable energy, especially wind and solar, including decentralised supplies. Thus, supply and demand must become more flexible through wider use of demand reduction, demand response mechanisms and energy storage. Currently, only several EU member states have regulatory and/or contractual measures that allow or promote different DR measures to be used for power system control [1].

Despite progress made over the years, corporations, municipalities and research institutions are still facing significant barriers to DEMO project implementation. Lack of executive or high-level regulatory support, staff/stakeholders expertise and funding are among such barriers.

This analysis is used as a preliminary study for DSM DEMO project planning in Latvia with the aim to identify possible flexibility of services, including DR, and determine the appropriate market design for such type of services to be implemented at the Baltic power system level, with the cooperation of DSO and TSO. Research was conducted in the Smart Grid Research Centre of IPE with the aim to facilitate national smart meter roll-out programme through knowledge transfer and support in smart grid technologies (SGTs), smart appliances and end-use device operational management to serve the consumer best needs [2].

2. DEMAND SIDE MANAGEMENT CONCEPTS AND ITS CONTRIBUTION TO POWER SYSTEM

2.1. General Concept and Terms

A number of EU and other national projects have demonstrated the utilisation of RES and DER flexibility within individual categories of grid connected devices, such as various types of domestic load, EV charging, storage with distributed generation [3]. The main challenges associated with smart grid operation are a coordinated approach and an optimal **energy management strategy** with respect to multiple objectives, where two main outcomes are:

- With a **new energy management solution (EMS)**, the wasteful use of energy will be decreased, and further **utilisation of RES** will be provided.
- With the developed EMS, a two-way digital communication between DSO and common household devices could enable smart energy system and advanced smart grid component management, **giving the prosumers a tool to improve their energy efficiency and actively participate in electricity market for lowering their costs of energy consumption.**

Another important part, before concept analysis consideration, is to consider the terminology used in the smart grid society and business case developers, for load management aggregation, over the world. Demand side management is understood as one of the key pillars of smart grids, where the role of load management takes the major place.

In respect to national case studies, the following two main definitions are used:

Demand Side Management (DSM) represents *a general category* of all end-user energy programmes that are often a set of dynamic tariffs or sustainable energy awareness strategies used to reduce consumption.

Demand Response (DR) is *a strategy* for energy consumption shaping, which aims at changing end-user consumption patterns according to system capacity and/or market requirements by altering the timing, the level of instantaneous demand or the total electricity consumption.

2.2. Price Responsive Demand

To research DSM specifics and investigate customer standpoint and behavioural barriers, the worldwide projects were analysed from the following countries: Austria, Canada, Denmark, France, Germany, Italy, Japan, Korea, South Africa, Sweden, the Netherlands and the USA [3]-[5].

Change of End-User Behaviour from Their Point of View

The two main lessons learned: 1) the need for the consumer personalised tool & services quality aiming towards maintaining the high level of the comfort, 2) smart network tariff should promote active consumers to participate in the system needs.

Finally, approaching the end consumers, the motivating factors should be carefully investigated and not be restricted to financial incentives. One of the positive ratings of the above-mentioned DEMO project analysis is that almost 80 % of involved consumers would like to continue DSM deployment.

Application of Smart Appliances and Home Automation System/Network (HAN)

SGT application for load management is mainly focused on the demonstration of the application of smart metering and developing monitoring and validation of concepts or the suggested approaches. Testing the role of information and communication technologies (ICT) in developing various concepts or security privacy issues is crucial in all DEMO projects. Therefore, the appropriate standardised instrument needs to be applied (Fig. 1).

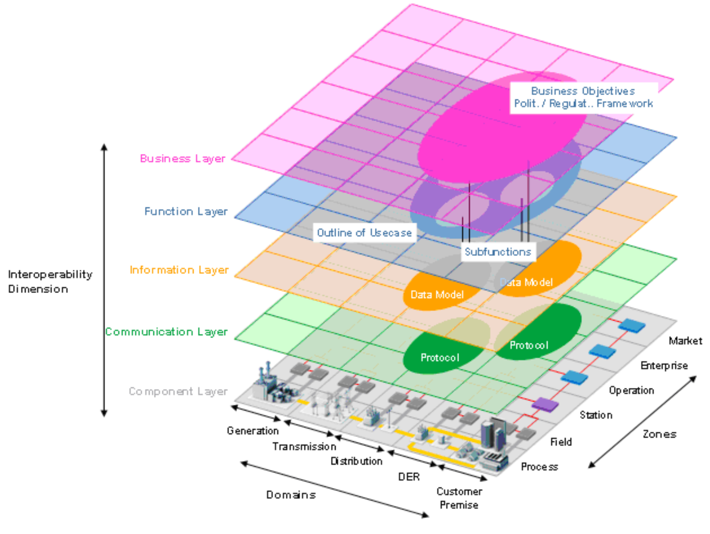

Fig. 1. SGAM (source: Smart Grid Coordination Group, "Smart Grid Reference Architecture", CEN/CENELEC/ETSI, 2012).

The **potential of direct load control** and demand reduction (including heating solutions) have also been estimated and suggested in order to shift flexible load automatically.

The main lessons learned, after calculating the theoretical potential, are as follows: load shedding is up to 50 % of peak demand when all buildings are equipped with an electrical heating system. Practically the load shedding potential is about 10 % of the peak load in the parts of the grid with a high density of installed electric heating and about 1.5 % of the peak load is shiftable within the existing legal framework [2]-[5].

Home automation system/network based on the multi-energy agent principle application aims at demonstrating the application of smart metering and developing monitoring solutions/applications and validation of concepts. Here the role of ICT is of great importance in developing various concepts or security and privacy issues. In order to optimally integrate active buildings into the smart distribution grid not only the voltage should be kept within the regulated marginal values, but also the available renewable resources should be optimally exploited.

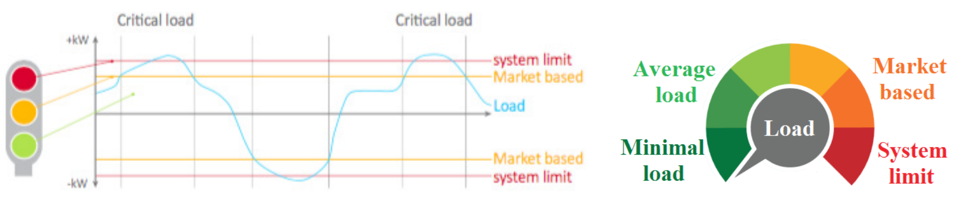

Fig. 2. Traffic-light model (source AIT and IPE).

In this regard the traffic-light model, for instance, can been suggested, in which active buildings react to the market signal as long as critical threshold values on the power grid are not reached (Fig. 2).

The **optimal energy management strategies** of smart metering & control, including deployment of the price responsive demand, aim at achieving the rational use of energy, demonstrating the first steps of implementation of home automation system with automated energy consumption scheduling units for load flexibility and controllable portion estimation.

Different DEMO projects have been carried out, which range from analysing the integration of renewables into distribution networks to assessing the impact of integration of electrical vehicles (EVs), residential consumers, buildings as well as commercial and industrial enterprises into the electricity grid. Therefore, **EV charging simulation** for an urban distribution network needs to be estimated at the DSO level, and symmetrical load distribution via three-phase charging should be adopted [6].

Purely market-oriented controlled charging, which leads to a high number of EV charging, at once should be avoided. In order to make the system as efficient as possible, a scheme or adaptive charging should be developed. Here, we can conclude that current **vehicle-to-grid delivery of electricity** is not feasible based on current market conditions, and the economic motivation for the EV participation in the electricity market needs to be developed in each particular DEMO project, taking into account regional tariff system and regulatory policy.

3. MARKET ESTABLISHMENT

All DEMOs were investigated taking into account the range of technologies under specific market rules. The target was to estimate if/how electricity markets provide the opportunities to realise value of (consumer) electricity to reduce the total demand.

Analysis of the above-mentioned DEMO projects shows that characteristic of every country and region should be investigated in order to identify the sources of flexibility and the nature of the market design in each case [3], [7]. The flexibility of the retail pricing schemes or the publication of sufficient balancing information is needed in order to trigger a reaction by the market actors or end-users through some examples of general guidelines.

Most DEMO projects have an objective of the proper integration of load from the residential sector and small industries in the balancing market. Besides, the investigated DEMOs take into account the fact that the capacity of the distribution grid can be a limiting factor in some cases due to security constrains:

- System change from a high level control of *small* number of large generation to *large* number of small/ medium distributed generation and flexible users.
- An extension of the market set-up is expected through the introduction of an ancillary services market.

The set-up of DSM ancillary services is also an important step in the further development of the existing electricity wholesale markets and balancing markets that create more favourable conditions for the integration of more renewable generation into the supply mix of energy resources.

Therefore, different electricity sub-markets and direct control mechanisms were investigated and the following market structure was proposed (Fig. 3) [7].

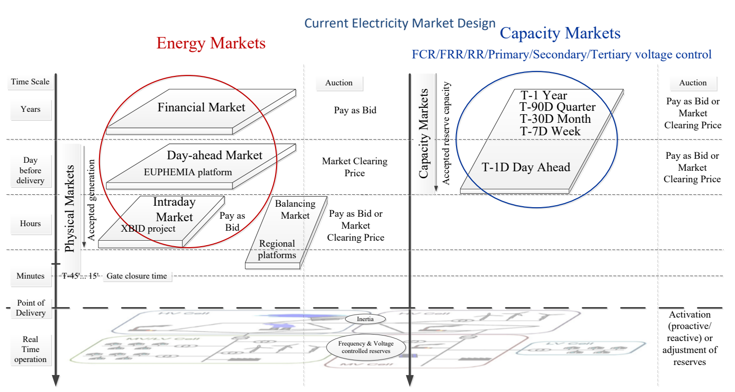

Fig. 3. The electricity sub-markets (source IPE).

To summarise DSM possible contribution to the existing electricity markets and further to balancing markets, the authors woud like to underline that the concept is to balance the power system by repeatedly issuing a price signal for exible resources to respond. The price signal will be continuously updated in order to keep the power system balanced, by increasing the price when there is a power deficit in the system, and vice versa. In the demonstration, the TSO is not issuing the price, as it would be the case in the real world. The price is distributed by a "price mechanism" that computes an artificial price, which is sent directly to the customer equipment and aggregators.

Therefore, in the major projects a real-time price signal can be used to activate flexible consumption. There are the cases with a significant peak load reduction potential: the activation of flexible consumption with a five-minute real-time signal reduces the total peak load of the project participants by approximately 1.2 % of the peak load. Another things that need to be mentioned are as follows: 1) the flexible demand response can be forecasted – with some certainty – resulting in overall improved system efficiency; 2) households, possessing equipment that controlled their heating system to respond automatically to price signals, accounted for 87 % of the peak load reduction [5].

4. DSM APPROACH AND TECHNIQUE ANALYSIS

This chapter provides the analysis of the implemented DSM approaches and techniques based on real case analysis. There are three main approaches to demand side management:

- The feedback system, which consists in **informing the consumer** about the system constraints. It focuses solely on providing feedback on the electricity use. This approach represents the first setup towards DSM implementation;
- The **price-based approach**, which requires behaviour change on the customer side triggered by price signals;
- The **system capacity-based approach**, which does not rely on the price sensitivity of customers, but on other system forecasts. In this approach, the customers indicate their preferences to a third party player (aggregator or system operator) and consent to let this player take the control of smart appliances. For larger customers this can include contracts for load shedding.

Load management classification from the perspective of **active and passive DSM techniques –** DSM covers large scope of techniques ranging from passive to active ones:

1. Basic passive techniques. Little to no control.
2. Active techniques. The consumer can opt-in or opt-out at any time.
3. Technique combination.

In the case of applied technologies, more standardisation can be required. It is a condition for the development of DSM; therefore, the following conclusions can be made in this chapter:

- Smart grids and DSM technologies should address standardisation and interoperability in order to improve business cases and assure the diffusion of the implemented solutions (see Fig. 1).
- In order to make DSM sustainable, the automation for load management is an important step. Customer engagement is an important part of DEMO programme application. More cooperation between DSM actors/players is required to provide the adequate services.
- Active and passive techniques of DSM can be implemented according to the DEMO targets.
- There is the need to provide the personalised advice/"tool".
- Ensuring smart technologies & new services truly beneficial for consumers, new technologies (such as AMI and HAN) must meet the necessary functionalities & interoperability to enable consumers to participate in load management and contribute to the markets.
- Consumer participation and flexibility in their consumption need to be properly rewarded.

5. BIG DATA ANALYSIS MODEL

Efficient load management and DER coordination require advanced automation schemes, accurate distribution system element monitoring and modelling with advanced Volt/VAR optimisation. This can be implemented by exploiting the large amount of data from the advanced metering infrastructure (AMI) [8].

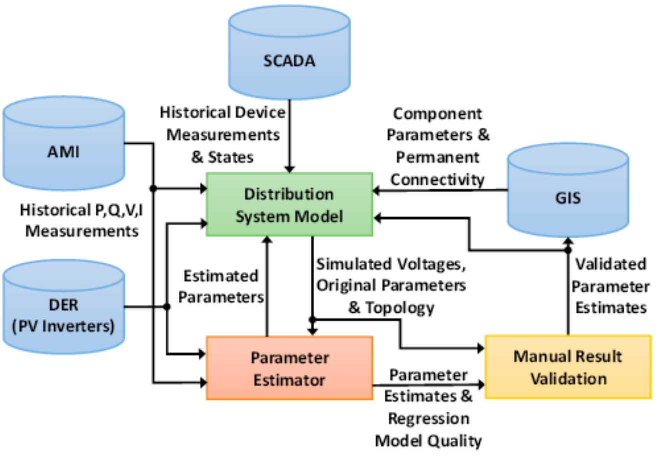

Fig. 4. BIG Data model for distribution system parameter estimation [8].

Therefore, with respect to the accuracy and quality, network topology and reliable control of all devices, implementation of the Big Data environment is of crucial importance. The practical estimation methods of computationally efficient distribution system parameters based on BIG Data model are used. The information flow is presented in Fig. 4:

- Current model components, parameters and permanent connectivity scheme will be imported from the GIS;
- SCADA will transmit the historical device measurement and states;
- AMI will provide load profiles;
- DER generation profiles as an input for the power flow simulation.

After passing manual validation, the estimated component parameters are passed to GIS and distribution system model. Such type of models plays an important role in validating and refining the existing DSO models, preparing them to the operational tasks for smart distribution systems.

6. CONCLUSIONS AND FURTHER RESEARCH

The tvelwe large-scale multinational demonstration projects have been investigated with the aim to study best practices of the stakeholders' experience, develop, promote and adapt smart grid tehnologies in Latvia and implement at the Baltic power system level, with the cooperation of distribution system operator (DSO) and transmission system operator (TSO). Several main conclusions and further research areas can be summarised as the *key findings*:

- As technologies have to be improved and system operators and companies have to become more strategic about how they direct spending, investments in energy efficiency result in significant decrease in greenhouse gases per dollar spent.
- Different approaches can be employed to recruit customers or the demonstrators depending on the expressed customer preferences and values as well as the current stage in the process of deploying DSM technologies in the country.
- Public trends and focus on the social values, and environmental aspects need to be included.
- Individual financial benefits and expectation affect DEMO challenges, and the contingency plan needs to be estimated.
- Consumer identification and lab validation selected use cases/ scenarios play an important and supporting role in the DEMO development.

Transfer of results, nature of intput need to be refined (technical specification requirement), and prelimenary stakeholder discussion is required with the aim to involve more partners from all cross sectors as parties of global smart grids.

ACKNOWLEDGEMENTS

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REFERENCES

1. European Commission. *Winter Package Heating and Cooling*. Available at https://ec.europa.eu/energy/en/content/winter-package-heating-and-cooling
2. Obushevs, A., Oleinikova, I., and Mutule, A. (2016). Demand side management platform for HAN flexibility estimation with agent control. In *13th International Conference on the European Energy Market "EEM16"*, Porto, Portugal. DOI: 10.1109/EEM.2016.7521185
3. Case Book 2014: Spotlight on Demand Side Management. International Smart Grid Action Network (ISGAN). Version 1.0
4. Smartgrids. Available at http://www.smartgridssalzburg.at/content/website_smartgrids/de_at/smartgrids.html
5. EcoGrid. Available at http://www.eu-ecogrid.net/
6. Grackova, L., Oleinikova, I., and Klavs. G. (20160). EV's charging in urban distribution network in active consumer concept. In *13th International Conference on the European Energy Market "EEM16"*, Porto, Portugal. DOI: 10.1109/EEM.2016.7521185
7. Obushevs, A., Oleinikova, I., and Mutule, A. (2015). Baltic transmission expansion planning considering wholesale electricity market. In *12th International Conference on the European Energy Market "EEM15"*, Lisbon, Portugal.
8. Peppanen, J., Reno M. J., Broderick R. J., and Grijalva, S. (2016). Distribution system model calibration with big data from AMI and PV inverters. *IEEE Transactions on Smart Grid, 7(5)*. DOI: 10.1109/TSG.2016.2531994

VIEDO TĪKLU ATTĪSTĪBA: MULTI-NACIONĀLO DEMO OBJEKTU ANALĪZE

I.Oļeiņikova, A.Mutule, A.Obuševs, N.Antoškovs

K o p s a v i l k u m s

Šodien enerģētikai tiek izvirzīti jauni mērķi: atjaunīgo energoresursu attīstība, kā no tehnoloģijas tā arī no tās pielietošanas viedokļa un vadības iespējām. Modernas, komplicētas sistēmas vadībai un attīstībai ir nepieciešamas jaunas viedās tehnoloģijas. Mainīga rakstura ģenerējošie avoti tiks savienoti ar tīkliem visos sprieguma līmeņos, un to vadībai ir nepieciešama radikāli jauna pieeja - ar reālā laika kontroli, augsto datu precizitāti un vadības iespējam.

Rakstā tiek apskatīta pieprasījuma vadības reakcijas (DSM) būtība, analizēta citu valstu pieredze pieprasījuma vadībā ar mērķi attīstīt, veicināt un piedāvāt tiem atbilstošu tirgus uzbūvi. Kā arī tiek piedāvāti iespējamie sistēmas pakalpojumu veidi, ko varētu īstenot Sadales Sistēmas Operatori un Pārvades Sistēmas Operatori Baltijas energosistēmas līmenī.

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INTRODUCTION OF ENERGY AND CLIMATE MITIGATION POLICY ISSUES IN ENERGY - ENVIRONMENT MODEL OF LATVIA

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The present research is aimed at contributing to the Latvian national climate policy development by projecting total GHG emissions up to 2030, by evaluating the GHG emission reduction path in the non-ETS sector at different targets set for emissions reduction and by evaluating the obtained results within the context of the obligations defined by the EU 2030 policy framework for climate and energy. The method used in the research was bottom-up, linear programming optimisation model MARKAL code adapted as the MARKAL-Latvia model with improvements for perfecting the integrated assessment of climate policy. The modelling results in the baseline scenario, reflecting national economic development forecasts and comprising the existing GHG emissions reduction policies and measures, show that in 2030 emissions will increase by 19.1 % compared to 2005. GHG emissions stabilisation and reduction in 2030, compared to 2005, were researched in respective alternative scenarios. Detailed modelling and analysis of the Latvian situation according to the scenario of non-ETS sector GHG emissions stabilisation and reduction in 2030 compared to 2005 have revealed that to implement a cost effective strategy of GHG emissions reduction first of all a policy should be developed that ensures effective absorption of the available energy efficiency potential in all consumer sectors. The next group of emissions reduction measures includes all non-ETS sectors (industry, services, agriculture, transport, and waste management).

Keywords: *bottom-up models, GHG abatement, energy efficiency, non-ETS, scenarios*.

1. INTRODUCTION

Taking into account the EU 2030 policy framework for climate and energy that has set an ambitious target – to reduce the EU domestic greenhouse gas (GHG) emissions in 2030 by at least 40 % compared to 1990, it is important that the member states assess the emissions forecast of the non-ETS sector in 2030, the impact of the planned emissions reduction measures on emissions volume and the possible strategies and costs for reaching the set targets.

In Latvia, a crucial part of the total emissions volume is made by emissions in the non-ETS sectors (GHG emissions from the sectors outside the EU Emission

Trading Scheme (hereinafter non-ETS sector) that constitute on average ¾ of the total emissions in the state. In Latvia, the non-ETS share in the total emissions volume is substantially higher than the EU average indicator 58 % [1]. Sources of emissions include the non-ETS sectors of agriculture and transport (except international aviation and international marine transport), and are not covered by the ETS energy, industry, household and waste management sectors. The transport and agriculture sectors gave most of the non-ETS emissions in 2014 (32.8 % and 30.3 %, respectively). The emissions share of the agriculture sector is essentially higher than the average EU indicator. Latvia had the lowest GHG emissions per capita in the EU in 2013, being almost by 40 % lower than the EU indicator. It is mostly determined by the large share of renewable energy sources (RES) in the gross final consumption of energy that reached 38.7 % in 2014 and ranks second in the EU after Sweden. This indicator is more than twice higher than the average indicator 16 % in the EU in 2014. An essential feature of the Latvian energy sector is the high ratio of district heating (DH). Slightly more than 55 % of dwellings are connected to DH. Households are the biggest consumers and in 2014 their share in the total DH consumption constituted almost 70 %. A note should be made that ETS companies supply about 70 % of the required heat in the DH system. Consequently, energy efficiency measures in buildings that at the EU level are believed to be typical GHG emissions reduction measures in the non-ETS sectors leave a vital impact on emissions of the ETS sector in Latvia.

The brief summary above about GHG emissions structure and some indicators in the energy sector and their comparison with the average EU indicators reveals the existing sharp differences between them and the need for assessing the strategies applying national models to reach the GHG emissions targets in Latvia.

2. MODELLING METHOD AND ASSUMPTIONS

To model the development of the Latvian energy sector and analyse the strategies for GHG emissions reduction in the non-ETS sector, we use widely-applied partial equilibrium, bottom-up, dynamic, linear programming optimisation model MARKAL code for the energy-environmental system optimisation [2], [3]. By adapting the model to Latvia's circumstances, the MARKAL-Latvia country model has been developed, which is applied to research energy and environment at the national level. The model integrates the end-use sectors and the supply side, holding descriptions of different energy sources and carriers that pass through the stages of energy system – transformation and distribution processes, energy end-use processes in all economic sectors, including a set of technological and energy efficiency options, as well as associated emissions. The approach of MARKAL Elastic Demand is used and a more detailed description of the Latvian model is given [4]. Alongside a very detailed description of the energy system, modelling of GHG emissions in other sectors (agriculture and waste management) and GHG abatement cost curves are presented. GHG emissions in the agriculture and waste management sectors are represented in aggregate, and it gives a possibility for an integrated assessment of the GHG emissions projection scenarios and the optimal strategy for reaching the aims set for Latvia concerning GHG emissions reduction. The developed version of the model allows modelling the interaction of the energy and agriculture sectors regarding the resources and energy used and the created and reduced GHG emissions. It includes the calculation of GHG emissions in full cycle use of biomass in energy production, for example, production of biogas and biofuel [5]. It provides a possibility to calculate in one model the created GHG emissions for the production of agricultural biomass and the reduced emissions in the energy sector, when substituting fossil resources. Such an approach gives a possibility to assess more accurately the impact of the implemented renewable energy resource policy upon the total GHG emissions in the country.

The historical import and export prices of energy carriers correspond to the data of the Eurostat external trade data base [8]. The trajectories of future price projections are smooth as to long-term trends; short-term prices may fluctuate relatively widely around the trajectory. The price projections of energy carriers are calculated on the basis of the IEA World Energy Outlook 2014 [9] fossil fuel import price projections from the "Current Policies Scenario".

3. RESULTS AND ANALYSIS

A set of scenarios was developed to serve as a basis for calculating GHG emissions projections and assessing the GHG emissions reduction policy and quantitative impact of the measures. The baseline scenario of GHG emissions projections envisages the implementation of those measures that are related to the climate policy and provided in the policy documents drawn by the Latvian government up to 2014. The same indicators were used in all scenarios to characterise the national economic growth (GDP growth, the development of sectors and industries (value added)), increase of population well-being (growth of private consumption) and demographic growth (see Table1). The scenarios differ in the selected energy and climate policy as well as the implementation or intensity regarding the measures of GHG emissions reduction. A brief characterisation of the scenarios modelled and used for further analysis of the results is given below:

- The baseline scenario aimed at reaching the targets of the existing energy and climate policy in 2020;
- GHG_00 scenario envisaging certain stabilisation of emissions in non-ETS sector at the level of 2005 beginning with the year 2030;
- GHG_10 scenario envisaging reduction of emissions by 10 % in the non-ETS sector against the level of 2005 beginning with the year 2030;
- Additional scenarios with additional available energy efficiency potentials (the above scenarios marked with E).

Based on assumptions about the changes in the indicators characterising the macroeconomic development by 2030, assumptions on changes in the fuel and energy prices, the energy and climate policies described in the model, the measures to be implemented for GHG emissions reduction the total GHG emission projections were calculated in the developed scenarios, which were further split into the ETS and non-ETS sectors. The table below presents GHG emissions projections were calculated in the non-ETS sector in the baseline and alternative scenarios.

Table 1

The Main Macroeconomic Indicators for GHG Emissions Projection in the Baseline Scenario

	2020	2025	2030	2035
Number of population in the middle of the year, thous.	1938.72	1926.85	1923.87	1924.47
Annual changes in private consumption, %	4.2 %	4.3 %	3.3 %	2.7 %
Annual changes of GDP, %	4.2 %	4.3 %	3.3 %	2.7 %
Agriculture	2.9 %	3.8 %	2.7 %	2.1 %
Services	4.8 %	4.6 %	3.4 %	2.7 %
Industry	5.1 %	6.7 %	5.6 %	4.4 %

Table 2

Summary of the Results on GHG Emissions in the Modelled Scenarios in the Non-ETS Sector

Scenario	GHG emissions in 2020 against the level in 2005	GHG emissions in 2030 against the level in 2005
Baseline scenario	+4.4 %	+19.1 %
GHG_00 scenario	+3.7 %	+0 %
GHG_10 scenario	+3.4 %	-10 %

To have an overall analysis of the volume of GHG emissions reduction in the alternative scenarios, their dynamics and distribution according to the sectors, the obtained modelling results in the alternative scenarios were compared to the results in the modelled baseline scenario. As revealed by the modelling results, the first emissions reduction measures in the alternative scenarios against the baseline scenario are to be implemented by 2020 (see Table 1). In the GHG emissions stabilisation scenario and the GHG emissions reduction scenario against the year 2005 measures with the greatest impact are implemented after 2025.

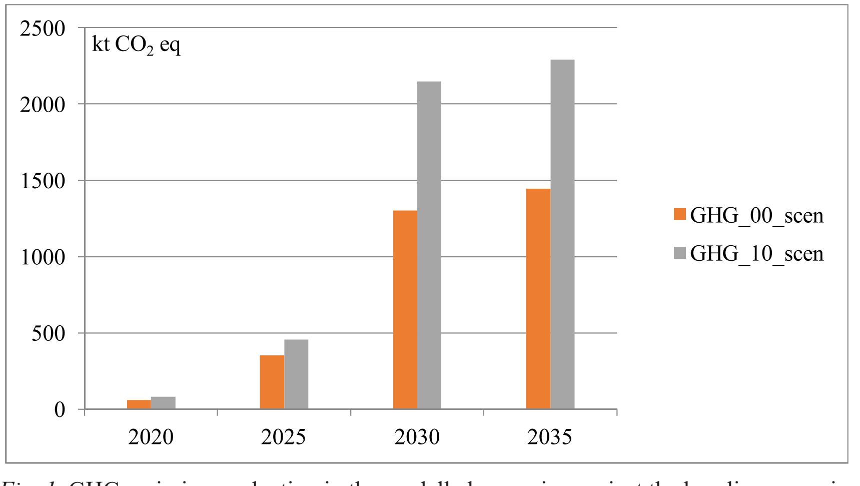

Fig. 1. GHG emissions reduction in the modelled scenarios against the baseline scenario.

The chart below reveals that the scenario on emissions stabilisation in 2030 against 2005 in comparison with the baseline scenario envisages measures of emissions reduction first in the industry (increasing energy efficiency and use of RES) followed by the transport and agriculture sectors. Measures of emissions reduction on a smaller scale are implemented in the services sector and households as in these sectors less costly measures are already implemented in the baseline scenario.

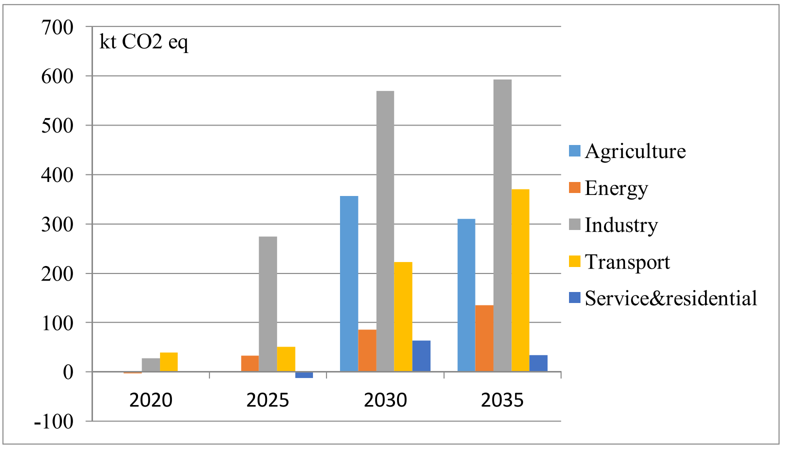

Fig. 2. GHG emissions reduction in the stabilisation scenario against the baseline scenario.

In the GHG emissions stabilisation scenario in 2030 against the baseline scenario the greatest contribution to the calculated 1301 kt CO_2 eq reduction is from reduction measures in the industry followed by the transport and agriculture sectors.

In case the non-ETS sector has set the target to reduce GHG emissions in 2030 against 2005 by 10 %, to reach the target, apart from the measures in the stabilisation scenario, the transport sector should contribute considerably to GHG emissions reduction after 2025 (see Fig. 3).

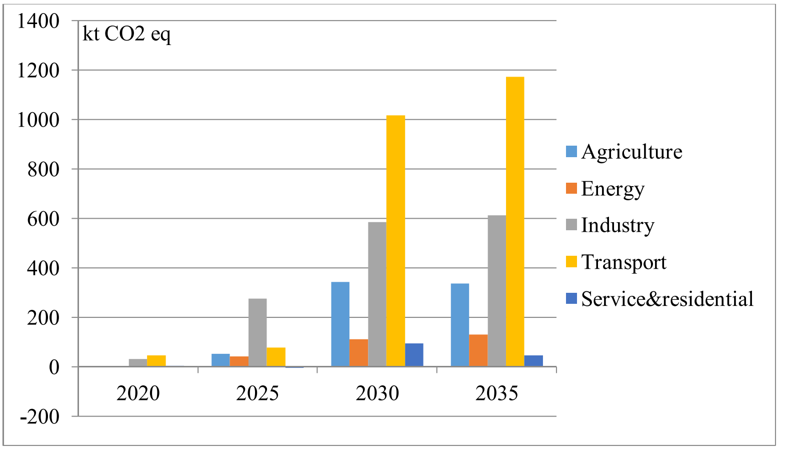

Fig. 3. GHG emissions reduction in the scenario with the 2030 reduction target against the baseline scenario.

As in the other sectors the GHG emissions reduction potential defined in the model is exhausted, bearing in mind the total optimal costs, the transport sector should provide almost half of the required GHG emissions reduction in 2030.

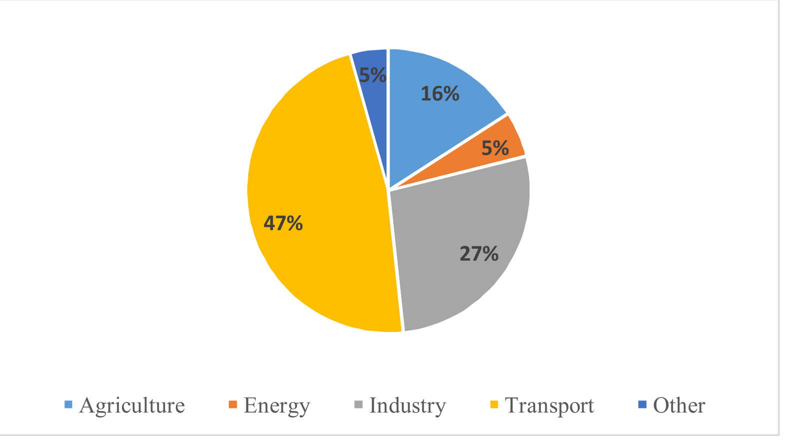

Fig. 4. Distribution of GHG emissions reduction according to sectors in the scenario with the 2030 reduction target against the baseline scenario.

Role of Energy Efficiency and Impact upon GHG Emissions Reduction

To assess the role of energy efficiency measures in GHG emissions reduction for reaching the targets, apart from the main set of alternative scenarios additional scenarios were developed (the scenario marked with E). In these scenarios, in addition to the already defined measures new packages of energy efficiency raising measures with additional potential and higher costs were included. Partly it can be interpreted as promoting the government policies by wider implementation of various energy efficiency raising measures. Figure 5 shows that in the GHG emissions stabilisation scenario these measures contribute to additional GHG emissions reduction in the services sector and households, thus substituting some more costly measures in the agriculture sector.

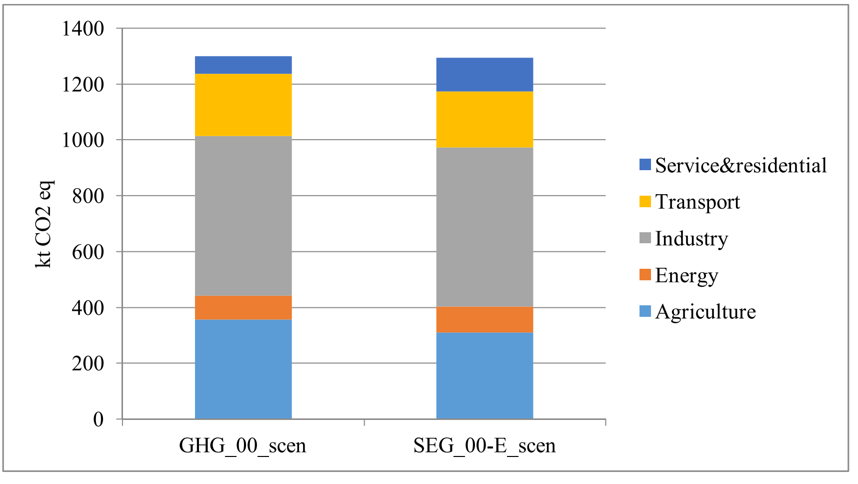

Fig. 5. Structure of GHG emissions reduction in the emissions stabilisation scenario in 2030 against 2005 based on a variety of available energy efficiency measures.

The scenario of GHG emissions reduction in 2030 against the level of 2005 envisages the implementation of additional energy efficiency measures in the services sector, households and industry. Thus, these measures substitute some more costly emissions reduction measures in the transport sector.

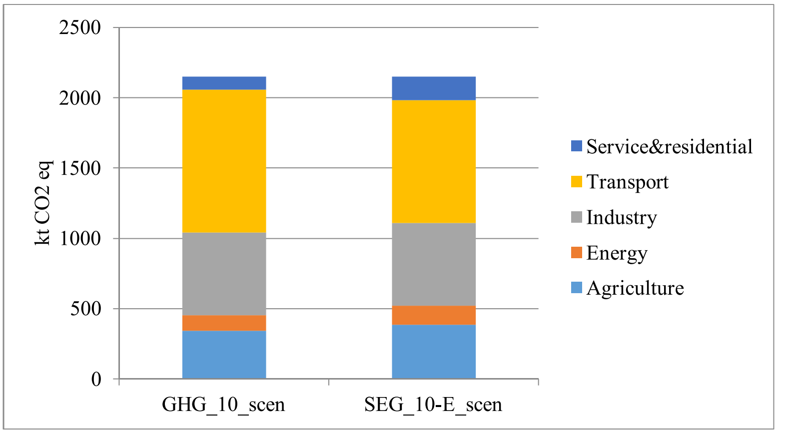

Fig. 6. Structure of GHG emissions reduction in the emissions reduction scenario in 2030 against 2005 based on a variety of available energy efficiency measures.

The modelling results reveal that additional energy efficiency measures in households are implemented to a full extent already in the GHG emissions stabilisation scenario (see Fig. 7). The results show that energy efficiency measures are cost effective for GHG emissions reduction with regard to the total optimal costs in the system.

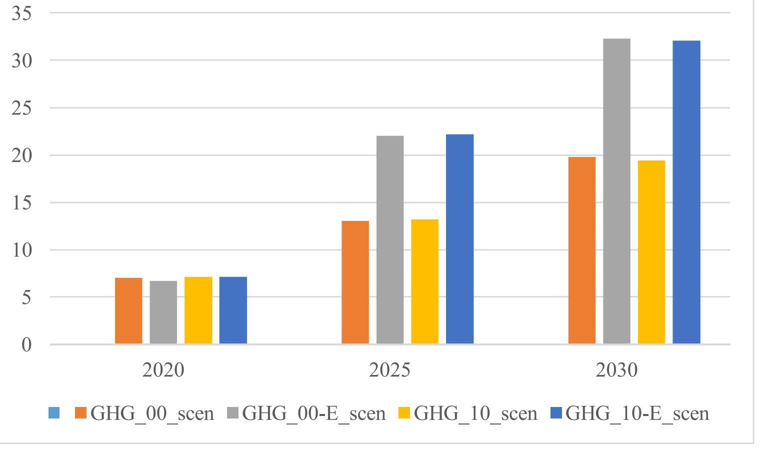

Fig. 7. Energy saved thanks to energy reduction measures in households in different scenarios.

Energy efficiency measures from the point of view of GHG emissions reduction abatement costs are among the measures with the lowest costs per reduced GHG unit (EUR/t CO_2 eq). At the same time, it should be admitted that to implement these measures many obstacles need to be overcome and various policies are to be applied for promoting these measures. Attractive emissions abatement costs for energy efficiency measures determine additional gains of emissions reduction from these measures, i.e., lower costs for energy and fuel consumption.

However, these measures often do not seem attractive to investors, as they are capital-intensive, i.e., with huge initial investments. In the actual investment environment with a limited amount of available investment, we are in a situation when an investor decides to invest in measures with lower capital intensity than in those with lower costs over the whole time period. In this way, the costs of emissions reduction measures increase continuously.

4. CONCLUSIONS

1. In the existing policy scenario (baseline scenario), the distribution of emissions among the sectors in the modelled non-ETS sector in 2030 is as follows: transport (31.3 %), agriculture (33.9 %), household and services (12 %), industry (9.4 %), energy (4.8 %), waste management (5.2 %) and the remaining part is formed by industrial processes and fugitive emissions, the use of solvents and other products.
2. The results obtained from the modelling of alternative scenarios allow making a conclusion that to reach the GHG emissions target in 2030 – to stabilise emissions at the level of 2005 or lower – it is necessary to implement the optimal scenario, i.e., to set higher GHG emissions targets in the non-ETS sector already for 2020. It is especially important in the scenario of emissions reduction in 2030 against the level of 2005.
3. On the basis of the modelling results, it can be concluded that to implement a cost effective strategy of GHG emissions reduction first of all a policy should be developed that ensures effective absorption of the available energy efficiency potential in all consumer sectors. The next group concerning GHG emissions includes measures that are to be implemented in all non-ETS sectors (industry, services, agriculture, transport, and waste management).
4. GHG emissions reduction in the non-ETS sector may fall into several sub-groups: (I) the energy and industry sectors where a relatively small number of participants operate and it is possible to influence their activities by developing an investment environment by means of regulatory instruments; (II) this sub-group includes sectors where consumers are involved, i.e., buildings, transport, and waste management. The number of participants here is very great and the emissions reduction potential is considerable and with relatively low costs, especially regarding the improvement of energy efficiency of buildings. It is essential to develop versatile support policies for GHG emissions reduction measures. (III) Many participants and many small sources create emissions in the agriculture sector. Emissions are calculated very vaguely and, therefore, it is difficult to assess the impact of measures.

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REFERENCES

1. Country Factsheet Latvia. (2015). *Commission staff working document*. Brussels, SWD 230 final.
2. Fishbone, L.G., and Abilock H. (1982). MARKAL, a linear programming model for energy systems analysis: Technical description of the BNL version. *International Journal of Energy Research*, *5(4)*, 353–375.
3. Loulou, R., Goldstein, G., and Noble, K. (2004). Documentation for the MARKAL family of models. Energy technology systems analysis programme. Available at http://www.iea-etsap.org/web/MrklDoc-I_StdMARKAL.pdf.
4. Klavs, G., Kudrenickis, I., and Rekis, J. (2015). Development of Latvia greenhouse gas reduction policy: Modelling and analysis. In *Proceedings of 5th International Multidisciplinary Scientific GeoConference SGEM* (pp. 921–932), ISBN 978-619-7105-38-4 / ISSN 1314-2704
5. Klavs, G., Kudrenickis, I., and Rekis J. (2015). Bio fuel contribution in meeting renewable energy and climate policy targets in Latvia. In *Proceedings of Conference "Engineering for Rural Development"* (pp. 490–496), ISSN 1691-5976
6. Eurostat International Trade Data Base. Available at http://ec.europa.eu/eurostat/web/international-trade/data/database.
7. IEA. (2014). World energy outlook 2014.

ENERĢĒTIKAS UN KLIMATA IETEKMES SAMAZINĀŠANAS POLITIKAS ASPEKTU IEKĻAUŠANA LATVIJAS ENERĢĒTIKAS - VIDES MODELĪ

G. Klāvs, J. Reķis

Kopsavilkums

Rakstā atspoguļoti rezultāti par pētījumu, kura mērķis ir sekmēt Latvijas ilgtermiņa klimata politikas veidošanu, aprēķinot kopējās siltumnīcefekta gāzu (SEG) emisijas līdz 2030. gadam, novērtējot SEG emisiju samazināšanas trajektorijas ne-ETS sektorā pie atšķirīgiem izvirzītiem emisiju samazināšanas mērķiem un salīdzinot iegūtos rezultātus ar ES definētiem mērķiem klimata un enerģētikas satvarā 2030. gadam. Pētījumā tika izmantots MARKAL-Latvija modelis, kas izveidots izmantojot augšupvērstā, lineārās programmēšanas, optimizēšanas modeļa MARKAL kodu, un kuram ir veikti papildinājumi klimata politikas integrētas novērtēšanas pilnveidošanai. Modelēšanas rezultāti par pētījumā izveidoto bāzes scenāriju, kas ietver Latvijas tautsaimniecības attīstības prognozes un esošos valsts klimata politikas noteiktos pasākumus, parādīja SEG emisiju pieaugumu ne-ETS sektorā 2030. gadā pret 2005. gadu par 19.1%. SEG emisiju stabilizācijas un samazināšana 2030. gadā pret 2005. gadu tika modelēti un analizēti alternatīvajos scenārijos.SEG emisiju stabilizēšanas un samazināšanas ne-ETS sektorā scenāriju modelēšanas rezultātu analīze atklāja, ka lai īstenotu no izmaksu viedokļa optimālu SEG emisiju samazināšanas stratēģiju, pirmkārt ir jāsekmē enerģijas efektivitātes pieejamā potenciāla izmaksu efektīva apgūšana visos enerģijas patērētāju sektoros un nākošā SEG emisiju samazināšanas pasākumu grupa aptver visus ne-ETS sektorus (rūpniecība, pakalpojumi, lauksaimniecība, transports, atkritumu apsaimniekošana).

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ENERGY ASPECTS OF GREEN BUILDINGS – INTERNATIONAL EXPERIENCE

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At present, reduction of greenhouse gas emissions is one of the main environmental priorities globally, and implementation of sustainability aspects in the construction industry, including energy aspects, is of major importance for long-term environmental development, as buildings have a long life cycle and require many resources both for construction and operation periods. The aim of the research is to analyse energy aspects of green buildings. The results of research show that the construction of green buildings can significantly result in energy savings and has other benefits for different market participants. Future research directions have been identified as well.

Keywords: *behaviour, construction, energy, energy efficiency, environment, green buildings, green materials, renewable energy, sustainability.*

1. INTRODUCTION

Improving energy usage in buildings is important for market participants at national, industry and company levels, and for every household as well. Implementation of green building concept includes a number of activities and is important because of great influence on consumption of resources, and especially energy resources, as the operation phase is the longest phase in the building life cycle. Energy solutions in green buildings can be an opportunity for investors and developers especially in long-term investments, and policies implemented in practice are an important step for solution to global environmental problems and achievement of millennium development goals.

The aim of the research is to analyse energy aspects of green buildings. The analysis, induction, logical access and literature review methods have been used in the research.

Growing population and high concentration of people as well as increased economic activities in urban areas have strengthened the link between cities, health and the environment, and the results of research indicate that green and sustainably renovated buildings can yield significant benefits in terms of energy and CO_2 reduction, cost savings, and improved health situation for building users [5]. It is important to note that a case study in the same research [5] has shown that buildings with the best two performances in Japan can achieve 33 % and 26 % reduction in energy use intensity, and 38 % and 32 % reduction in CO_2 emissions intensity in comparison with benchmark values. In the analysis of green building aspects in India [24], a method has been proposed, which can help increase a green building index by achieving more green points at less cost, and apart from technological parameters, socio-economic and construction strategies have also been analysed.

The ***object of the research*** is energy aspects in green buildings. ***The subject of research*** is green building development issues. The research includes international experience worldwide, including case of Latvia. As green buildings cover a variety of aspects, and as construction is a complicated process that influences and involves a number of different market participants, the research covers interdisciplinary aspects.

2. OVERVIEW OF THEORETICAL ASPECTS AND INTERNATIONAL EXPERIENCE OF POWER ENGINEERING ASPECTS IN GREEN BUILDING PRACTICES

Construction industry is one of the largest final consumers of environmental resources and one of the largest emitters of greenhouse gases and other types of pollution, but until the 21st century, for instance, in China, green building construction has not received much attention [15]. Currently, green building construction is considered to be an essential practice for achieving sustainability [24].

The usage of term "green building" has increased rapidly after implementation of green building certification; however, the idea of implementation of green building aspects in different areas has appeared earlier. Green building is defined as "the practice of: 1) increasing the efficiency with which buildings and their sites use energy, water, and materials, and 2) reducing building impacts of human health and the environment, through better siting, design, construction, operation, maintenance, and removal throughout the complete life cycle" [16].

Findings also identify that 43 % of the annual reduction in terms of energy consumption and energy expenditures for a typical American home with green building technologies can be observed, and energy efficiency performance of green building technology may differ depending on energy consumption-related resident behaviour [27]. In the other case study, development of multigeneration system of integrating renewable energy sources for a green house, the total net present cost for the optimised power system and wind turbines is found to be $345,481, with 100 % renewable fraction and no emissions of carbon dioxide or other pollutants, when the exergy efficiency is found to be 7.3 % for the system, and the energy efficiency is 46.1 % [13].

At the same time, according to the research on risk perception of the life cycle of green buildings in China, Xuan Qin, Yiyi Mo, and Lei Jing [18] have found that while a variety of benefits of green construction have been recognised, the risks associated with green buildings have not been addressed appropriately. As a result, among 56 risk factors, 36 are perceived as key risk factors affecting the success construction of green buildings (for example, political risks, certification risks, financial and/or cost risks, quality and/or technological risks, social risks and managerial risks), including bureaucracy, inappropriate green building maintenance, lack of green building design activities, high price of green building materials and other risks. The differences in risk importance to different stakeholders have also been identified.

In the estimation of dwelling energy consumption and the interpretation of the energy performance analysis, the results suggest adding to the analysis building related data and thermal modelling, urban geographical modelling, including socio-economic aspects, landscape and micro-climate [6]. Sustainable building performance requires behavioural aspects and interaction of elements such as movement patterns of people, indoor and outdoor conditions, walkability, social, psychological, or economic drivers of behaviour formation and change, as well as the micro-modelling of specific behaviours of occupants within their built environment [4]. They can also affect use of usergy. The research results on the analysis of the potential of energy savings in the Chinese building materials industry under different economic growth scenarios [17] show that a 1 % increase in technological progress, energy price and per capita productivity will produce respectively 1.1684 %, 0.8056 % and 0.3649 % decrease in the sectoral energy usage. The results also show that the potential of sectoral energy savings is one of the improvement opportunities.

Building design, as a building material, is of great importance in energy saving activities. A multi-objective optimisation model was developed [25] and included several conflicting criteria such as economic and environmental performance that could assist designers in green building design. Many studies on passive solar buildings demonstrated that the application of phase change heat storage materials could decrease the variation in the air temperature in the room, including decrease in energy consumption for maintenance of comfort temperature levels in buildings [12].

Energy consumption issues are important for sustainable long-term development of country and its environment. Special attention should be devoted to climatic aspects and seasonal characteristics of each country. Over-arching renewable energy associations in Latvia are as follows [23]:

- Latvian Biomass Association (LATBIO);
- Latvian Biogas Association;
- Wind Energy Association;
- Small Hydropower Association;
- Solar Energy Association;
- Latvian Bioenergy Association;
- Wind Energy Producer Association;
- Latvian Renewable Energy Confederation;
- Latvian Institute for Sustainable Development and other.

In a particular case in Latvia, the use of solar collectors can reduce utility bills by 30 % [20]; however, the potential of solar energy in Latvia is low, but it can be comparable with many European countries, where solar panels are used widely, and practice shows that for the production of electricity, solar radiation is used rather than heat. The same research shows dependence of conventional energy on the wind speed, including the fact that it is possible to use only 59.3 % of kinetic energy of the wind ("the limit of Betz-Zhukovsky") because the maintenance of the air flow is required for all wind machines. In the operational practice of solar pump "Saules-sukni" EKTOS heating system, by using vacuum solar collectors TS400, there is a possibility to save up to 85 % of the energy consumed for heating and hot water [21].

Scientists of the Institute of Industrial Electronics and Electrical Engineering, Faculty of Power and Electrical Engineering (Riga Technical University) in cooperation with the German automobile company Daimler AG developed a unique direct current (DC) power supply system, which would save up to 15 % of electricity. At present, the world manufactures the alternative current (AC) mains, but in Riga the first laboratory has been set up where the electricity supply is used for direct current (DC) energy [19]. A major benefit of the solar water heater has been found that it is possible to save more money with a solar water heater than, for example, by investing the money in a low-risk fixed deposit account, including such aspects as investment interest rate of 6 %, high electricity inflation and consumer price inflation [26].

Recently researchers have found that pollution reduction can reinforce firm competitiveness by better access to the market, selling pollution reduction technologies, differentiating products because of better risk and stakeholder management, reduction of costs in materials, labour, and capital [3]. It has been analysed that internal rates of return grow with energy improvement actions [8]. Green building development can have a variety of reasons, for example [7, p. 3065]:

- Lower operation costs;
- Higher building value;
- Lower lifetime costs;
- Higher return on investment (ROI);
- Help in transforming the market;
- Increased staff productivity and retention;
- Enhanced marketability;
- Reduced liability and risk.

For modernisation of housing stock in general, there are European funds, which finance up to 85 % of the cost of the project. The financing measures of the European Union can be divided into 2 groups: measures for energy saving and purpose of the measures [14]. Table 1 demonstrates the energy saving measures in prefabricated buildings.

On example of green building analysis in Hong Kong and Singapore [7], such contractionary criteria as higher upfront costs, lack of education, lack of fiscal incentives and lack of awareness can appear, but issues such as "lack of coordination and consistency in rating tools and standards", "lack of research", or "unrecognised eco-labelling" are seen by a few building designers as the main obstacles to green building construction. One of the novelties in green building certification is the green building assessment tool integrated with BIM that can help the design team in the generation of necessary documentation to obtain green building certification [11]. However, socio-economic aspects still are important as they indicate well-being of society [10], and socio-economic aspects are especially important for green building construction and realisation opportunities. Green building certification is an indicator that can show building performance by many parameters, and the number of certified green buildings is increasing worldwide.

Implementation of green building technologies can reduce consumption of energy during the operation phase. The market size and structure of companies operating in it are also important. In such a way, the combination of economic and technical aspects can assist in energy planning activities at different levels.

Table 1

Energy Saving Measures in Prefabricated Buildings [14, pp. 144–145]

Energy saving measures	Purpose of the measures
Basic measures	
Insulation: exterior walls, cellar ceiling, ceiling over last living compartment	Reduction of heat losses through the outer part of the building
Installation of insulation	Unnecessary heat losses in the installation must be avoided
Replacing windows Ventilation slots Fittings for ventilation in the window	Reduction of heat losses due to formed surfaces, frames Unnecessary heat losses (due to uncontrolled air supply through cold window fittings) Sufficient air exchange rate
Accompanying measures	
Heating system modernisation	Weekly supplied hot water heating as required (according to reduced heat demand after heat insulation)
Modernisation of heating pipes and radiators	More precise regulation according to the requirements in the apartments
Counters on radiators	The use of the apartment (billing according to consumption) to avoid overheating the apartment
Renovation of the staircase	Effective element of modernisation (age friendly)
Other (additional) measures	
Energy certificates and energy balance	Incentive for the owner to carry out measures for energy saving, since this offers a favourable argument during negotiation or sale
Renewable energy	Heat recovery devices (e.g., the use of heat from waste air and wastewater): - Thermic solar systems (for preheating of heating system water and hot water) - Photovoltaic devices - Decentralised heat generation with cogeneration

3. RESULTS AND DISCUSSION

Results have shown that there is a high necessity for green building construction, but at the same time there are a number of risks and conflicting criteria during its implementation. It is suggested to select strategies with high energy efficiency at the design and operation stages of green buildings. It is suggested that clients should cultivate proper behaviour in terms of energy efficiency, and at the same time government preferential policies and financial incentives should motivate green building development to solve this conflict between cost and functions, and in this case post occupancy evaluation can be recommended [22]. Often more developed areas in ecological performance perform better than less developed areas mainly due to a higher technological level [15]. Thus, energy efficiency plan development at the regional level is important [1]. Certification systems alone cannot be enough to promote widespread development of green buildings, and it is also recommended to change energy and water consumption behaviour [5]. In successful implementation of green building methods, all stakeholders including architects, engineers, and contractors would benefit from a comprehensive framework that incorporates green building technologies and technologies during all phases of building life cycle [2]. Successful implementation of energy efficiency activities in green buildings requires involvement of many participants during different phases of building life cycle, but it is also important to implement all activities in a timely manner.

4. CONCLUSIONS

1. As economic, social and environmental aspects are interrelated, special attention should be devoted to all these aspects by all market participants, at all levels, and it is also necessary to analyse different consumer groups, especially in green building planning and its energy aspects. As economic and environmental aspects can be conflicting, there is also a necessity to implement green building motivating activities in the practice, for example, government support programmes.
2. For entrepreneurs, house managers and other market participants, it is recommended to regularly make energy audits, as it can help detect problems and find possible solution opportunities at early stages.
3. Optimal balance of integration of green building criteria in the construction process without limitation of construction industry development should be found. Future research directions involve the integration of ecological and green building aspects in environmental models at different levels.

REFERENCES

1. Actiņa, G., Geipele, I., and Zeltiņš, N. (2014). Role of building thermal inertia as a selection criterion of edifice renovation strategy and energy plan development in Latvia: Case study. In *Proceedings of the 2014 International Conference on Frontier of Energy and Environment Engineering (ICFEEE 2014) / ed. by Wen-Pei Sung, Jimmy (C.M.) Kao*, Taiwan, Taiwan, 6–7 December 2014. Leiden: CRC Press/Balkema, 2014, pp. 361–365. ISBN 978-1-138-02691-9. e-ISBN 978-1-315-73991-5. DOI:10.1201/b18135-73
2. Ahn, Y.H., Jung, C.W., Suh, M., and Jeon, M.H. (2016). Integrated construction process for green building. *Procedia Engineering, 145,* 670–676. DOI: 10.1016/j.proeng.2016.04.065
3. Ambec, S., and Lanoie, P. (2008). Does it pay to be green? A systematic overview. *Academy of Management Perspectives, 22*, 45–62, as cited in Chen, P.-H., Ong, C.-F., & Hsu, S.-C. (2016). Understanding the relationships between environmental management practices and financial performances of multinational construction firms. *Journal of Cleaner Production. 139,* 750–760. http://dx.doi.org/10.1016/j.jclepro.2016.08.109

4. Azar, E., Nikolopoulou, C., and Papadopoulos, S. (2016). Integrating and optimizing metrics of sustainable building performance using human-focused agent-based modelling. *Applied Energy, 183,* 926–937. http://dx.doi.org/10.1016/j.apenergy.2016.09.022
5. Balaban, O., and Oliveira, J. A. P. (2016). Sustainable buildings for healthier cities: Assessing the co-benefits of green buildings in Japan. *Journal of Cleaner Production. Article in Press,* 1–11. http://dx.doi.org/10.1016/j.jclepro.2016.01.086
6. Calderón, C., James, Urquizo, J., and McLoughlin, A. (2015). A GIS domestic building framework to estimate energy end-use demand in UK sub-city areas. *Energy and Buildings, 96,* 236–250. http://dx.doi.org/10.1016/j.enbuild.2015.03.029
7. Chan, E.H.W., Qian, Q.K., and Lam, P.T.I. (2009). The market for green building in developed Asian cities – The perspectives of building designers. *Energy Policy, 37,* 3061–3070. DOI:10.1016/j.enpol.2009.03.057
8. Christersson, M., Vimpari, J., and Junnila, S. (2015). Assessment of financial potential of real estate energy efficiency investments – A discounted cash flow approach. *Sustainable Cities and Society, 18,* 66–73. http://dx.doi.org/10.1016/j.scs.2015.06.002
9. European statistics database Eurostat. *Statistics database*. Retrieved from http://ec.europa.eu/eurostat/data/database
10. Geipele, I., Geipele, S., Staube, T., Ciemleja, G., and Zeltins, N. (2016). The development of nanotechnologies and advanced materials industry in science and entrepreneurship: Socioeconomic and technical indicators. A case study of Latvia (Part Two). *Latvian Journal of Physics and Technical Sciences, 53(5),* 31–42. DOI: 10.1515/lpts-2016-0034
11. Ilhan, B., and Yaman, H. (2016). Green building assessment tool (GBAT) for integrated BIM-based design decisions. *Automation in Construction*. *70*, 26–37. http://dx.doi.org/10.1016/j.autcon.2016.05.001
12. Kenisarin, M., and Mahkamov, K. (2016). Passive thermal control in residential buildings using phase change materials. *Renewable and Sustainable Energy Reviews. 55,* 371–398. http://dx.doi.org/10.1016/j.rser.2015.10.128
13. Khalid, F., Dincer, I., and Rosen, M.A. (2016). Techno-economic assessment of a renewable energy based integrated multigeneration system for green buildings. *Applied Thermal Engineering, 99,* 1286–1294. http://dx.doi.org/10.1016/j.applthermaleng.2016.01.055
14. Krasowska, K., and Olczyk, N. (2015). Energieprobleme mit Plattenbauten [Energy Problems in Prefabricated Buildings]. In Schmidt, B., Schmidt, D., & Venymer, H. (Hrsg.) *Energieökonomisch* Wohnen: 9. Konferenz Solarökologische Bausanierung im SolarZentrum Mecklenburg-Vorpommern. Internationale Konferenz Solarökologische Bausanierung [Energy Economical Living: 9th Conference Solar Ecological Building Restoration in the Solar Center Mecklenburg-Vorpommern], pp. 135–148, 2015, Lübow-Wietow. Berlin Wien Zürich: Beuth Ltd.
15. Liua, H., and Lin, B. (2016). Ecological indicators for green building construction. *Ecological Indicators, 67*, 68–77. http://dx.doi.org/10.1016/j.ecolind.2016.02.024
16. Office of the Federal Environmental Executive (2003). The Federal Commitment to Green Building: Experiences and Expectations. As cited in Marble institute. Green building – History of Green buildings. Retrieved from http://www.marble-institute.com/default/assets/File/consumers/historystoneingreenbuilding.pdf
17. Ouyang, X., and Lin., B. (2015). Analyzing energy savings potential of the Chinese building materials industry under different economic growth scenarios. *Energy and Buildings, 109,* 316–327. http://dx.doi.org/10.1016/j.enbuild.2015.09.068
18. Qin, X., Mo, Y., and Jing. L. (2016). Risk perceptions of the life-cycle of green buildings in China. *Journal of Cleaner Production, 126, 148–158.* http://dx.doi.org/10.1016/j.jclepro.2016.03.103

19. RTU Marketing and Communication Department (2016). RTU radītā unikālā līdzstrāvas elektroapgādes sistēma ļaus ietaupīt līdz 15% elektroenerģijas [Unique DC Power Supply System Created at RTU will save up to 15 % of Electricity]. Retrieved from https://ortus.rtu.lv/f/u10111s187/p/rtu-jps-arhivs.u10111n201/max/render.uP?pCm=view&pP_action=article&pP_id=22777#Pluto_151_u10111n201_9678_container
20. Sakipova, S., Jakovics, A., Gendelis, S., and Buketov, E.A. (2016). The potential of renewable energy sources in Latvia. *Latvian Journal of Physics and Technical Sciences*, *53(1)*, 3–13. DOI: 10.1515/lpts-2016-0001.
21. Saulessūknis. Solārās apkures sistēma [Saulessuknis. A solar heating system]. (2015). http://saulessuknis.lv_as cited in Sakipova, S., Jakovics, A., Gendelis, S., & Buketov, E.A. (2016). The potential of renewable energy sources in Latvia. *Latvian Journal of Physics and Technical Sciences*, *53*(*1)*, 3–13. DOI: 10.1515/lpts-2016-0001.
22. Shi, Q., Yan, Y., Zuo, J., and Yu, T. (2016). Objective conflicts in green buildings projects: A critical analysis. *Building and Environment, 96,* 107–117. http://dx.doi.org/10.1016/j.buildenv.2015.11.016
23. Vigants, E. (2014). Renewable energy in Latvia. In *Conf. Renewable Energy in the Baltics and the Future of European Energy Security*, Washington, DC, December 15, 2014. Retrieved from https://us.boell.org/sites/default/files/uploads/2015/02/edgars_vigants_laef_prezentation_washington_ev_final.pdf
24. Vyas, G.S., and Jha, K.N. (2017). Benchmarking green building attributes to achieve cost effectiveness using a data envelopment analysis. *Sustainable Cities and Society, 28,* 127–134. http://dx.doi.org/10.1016/j.scs.2016.08.028
25. Wang, W., Zmeureanu, R., and Rivard, H. (2005). Applying multi-objective genetic algorithmsin green building design optimization. *Building and Environment,* 40, 1512–1525. DOI:10.1016/j.buildenv.2004.11.017
26. Wing, S.N.C., Canha, D., and Pretorius, J.H.C. (2015). Residential solar water heating - Measurement and verification. Case studies. In *8th International Conference on Energy Efficiency in Domestic Appliances and Lighting.* 26–28 August 2015, Lucerne-Horw, Switherland. Retrieved from https://iet.jrc.ec.europa.eu/energyefficiency/sites/energyefficiency/files/events/EEDAL15/S15_Heating-cooling-1/eedal15_submission_90.pdf
27. Zhao, D., McCoy, A., and Du, J. (2016). An empirical study on the energy consumption in residential buildings after adopting green building standards. *Procedia Engineering, 145,* 766–773. DOI: 10.1016/j.proeng.2016.04.100

ENERĢĒTIKAS ASPEKTI ZAĻAJĀ BŪVNIECĪBĀ – STARPTAUTISKĀ PIEREDZE

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K o p s a v i l k u m s

Šobrīd siltumnīcefekta gāzu emisiju samazināšana ir viena no galvenajām vides prioritātēm visā pasaulē, un ilgtspējīgas attīstības aspektu īstenošanai būvniecības nozarē, tostarp enerģijas aspektu īstenošanai, ir augsta nozīme ilgtermiņa vides attīstībā, jo būvniecības objektiem ir ilgs dzīves cikls un to būvniecība pieprasa daudz resursu, gan būvniecības, gan ekspluatācijas fāzēs. Pētījuma rezultāti rāda, ka zaļā būvniecība var radīt būtisku enerģijas ietaupījumu, ka arī var sniegt vairākus citus labumus un iegūvumus vairākiem tirgus dalībniekiem vairākos līmeņos. Pētījumā tika identificēts arī nākamo pētījumu virziens.

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PERFORMANCE EVALUATION OF PHOTOVOLTAIC SOLAR AIR CONDITIONING

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Information on the electrical-driven solar air conditioning (SAC) is rather scanty. A considerable body of technical data mostly concerns large-scale photo-voltaic solar air conditioning (PV-SAC) systems. Reliable information about the energy output has arisen only in recent years; however, it is still not easily accessible, and sometimes its sources are closed. Despite these facts, solar energy researchers, observers and designers devote special attention to this type of SAC systems. In this study, performance evaluation is performed for the PV-SAC technology, in which low-power (up to 15 kW_p of cooling power on average) systems are used. Such a system contains a PV electric-driven compression chiller with cold and heat sensible thermal storage capacities, and a rejected energy unit used for preheating domestic hot water (DHW). In a non-cooling season, it is possible to partly employ the system in the reverse mode for DHW production. In this mode, the ambient air serves as a heat source. Besides, free cooling is integrated in the PV-SAC concept.

Keywords: *solar energy, electrical-driven, solar air conditioning, performance evaluation.*

1. INTRODUCTION

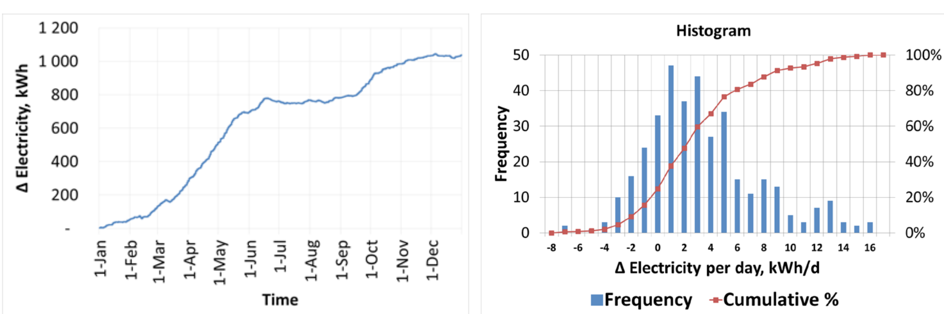
Expected increase in the cooling loads for comfort needs in private and office buildings calls for alternatives to the conventional energy sources in order to reduce global greenhouse gas emissions, e.g., CO2. Reduction in the component costs and innovative solutions in the area of solar energy technologies open wider opportunities for their application in different building sectors. The solar cooling communities from SHC IEA report about the increase in the number of solar cooling and air conditioning systems in the last decade. These authors offer several ways for conversion of the solar radiation into cold using solar cooling components. Today, the most popular technologies are thermal-driven ab- and adsorption chillers in combination with solar thermal collectors. However, due to high costs of the sorption machines and collectors, the market for these technologies is growing very slowly. At the same time, the photo-voltaic (PV) market develops fast, with continuously reduced PV module prices. This economical reason increases the attractiveness of solar-electrical air conditioning systems. Therefore, the coupling of PV modules with an electrical-driven system of the type presents the concept of PV-based air conditioning. It should be noted that all components of PV electricity driven air conditioning systems are commercially available.

Electric-driven heating and cooling equipment, such as vapour compression heat pumps (HPs), chillers or reversible HPs, in connection with hot and/or cold storages is an attractive option for the energy supply in buildings. However, except for some European regions, today only a few complete system solutions using photovoltaics for the energy supply in buildings are available on the market. Therefore, a lack of information on the overall cost and performance of such systems is identified.

2. PERFORMANCE EVALUATION

The experimental results [1] confirm the operability of PV-SAC technology. Additionally, the parameters of operation under critical conditions have been obtained. The experiments have shown appropriate functionality of the system at temperature and power fluctuations. Even in critical situations no failures of the system's inside and outside components took place. Stable and predictable operation of the system was also observed in the autonomous regime.

The simulation results show that the full cooling demand can be covered using PV-SAC technology in a standard single-family house. It has been found that PV power is sufficient for the maximum electricity consumption of the system. The results show that for effective use of PV-generated power the electricity accumulation is needed.



a) b)

Fig. 1. Imbalance of electricity generation (+) and electricity consumption (-) of the system (Δ Electricity): a) cumulative annual result, b) daily results of one-year operation.

Figure 1a shows imbalance between the electricity generation by the PV array and the electricity consumption by the cold production and distribution component of the system. It is seen that such imbalance is more stable in a cooling season in compliance with the design of PV and SAC components. For DHW preheating in a non-cooling season, the reverse mode is used. Higher electricity overproduction is observed in the inter-seasonal periods, which is due to combination of high PV electricity generation and freezing protection. Enhancement of defrosting the outdoor air-water heat exchanger leads to a significant decrease in the electricity overproduction. The daily electricity imbalance seen in Fig. 1b is from -3 kWh/day to +9 kWh/day in 90 % of the days. The installation of an electrical accumulator with the capacity of at least 6 kWh covers periodical electricity overconsumption in a cooling season. Decreasing the accumulator capacity exponentially increases the cooling deficit up to 41 %.

Electricity unavailability might lead to immediate shutdown of the system. Such being the case, first of all the heat from the hot side of cooling machine should be rejected, while its cold side should be protected from freezing. For this purpose, two circulation pumps continue operation after the compressor stops. Second, the prepared cold should be distributed, for which electricity is also consumed. Respectively, PV-SAC operation without electricity accumulators will extremely reduce the lifetime of the system as well as its efficiency. Moreover, this may cause unrecoverable destruction of the system components.

The thermal energy storages allow smoothing the peaks of cold production and heat rejection, thus reducing the load of cooling machine and improving its performance. The heat production and redirection are also possible owing to hot storage implementation. Our results show that 26 % of rejected heat is redirected to the DHW heating, with the heat needs for DHW fully satisfied by PV-SAC in a cooling season.

High cold preparation performance is achieved by free cooling. Unfortunately, free-cooling regime could be limited by weather conditions.

3. FINANCIAL PROFITABILITY ASSESSMENT

In the financial profitability assessment, the results for PV-SAC yield are used. In the reference building and under reference conditions, the PV-SAC technology meets a cold demand of 5 MWh/a and a heat demand of 2.6 MWh/a. Additionally, 1 MWh/a of electricity is generated.

The initial investment in PV-SAC is with 5 kW cooling power 1 700 Euro. Additional costs of the high precision measuring equipment are excluded as not required in conventional PV-SAC applications.

Thermal insulation is included. Thermal storages are pre-insulated. The cooling machine contains two circulation pumps. The CM-integrated control unit is able to control the operation of compressor, the cold side and the cold side circulation pumps, and the outdoor unit. To control the operation of cold distribution pump, mixing valve, three-way valves as well as the free-cooling mode, an additional control unit is required.

The installation costs are highly variable due to several reasons. First, these costs depend on the particular location and building type. Second, they depend on the salary level in the engineering sectors in the particular region. Third, the costs of equipment to be installed are determined by its class. Future widespread applications of PV-SAC technologies would improve the workmanship, thus reducing the installation costs. In the financial profitability assessment, the estimated average costs of PV-SAC installation in European regions are applied.

Maintenance costs include periodical system's check and adjustment. Brine should be replaced every 7 years of system operation. The lifetime of the main system part is 20 years. Three circulation pumps have a shorter lifetime: they should be replaced after 10 years. Respectively, the average maintenance costs are 87 Euro per year.

The financial profitability of PV-SAC is assessed in comparison with the conventional air conditioning and heating (CAC&H). The cost of a split-type CAC system with the COP rate of 3.0 is 1200 Euro including installation, and its average lifetime is 5 years.

The average price of electricity for household consumers in the EUmix (the prices for 28 European Union member states are weighed according to their consumption by the household sector) was 0.208 Euro per kWh in the second half of 2014 [2]. The price of heat energy includes the natural gas price and takes into account the efficiency of boiler. In the second half of 2014, the price of natural gas for a medium-sized household within the EUmix was 0.072 Euro per kWh [2], with the average efficiency of a residential boiler being in proximity to 90 % [3] of the annual fuel utilization efficiency.

In the assessment above, the installation cost of auxiliary heating is not included, since PV-SAC generates heat only periodically. The PV overproduced electricity of up to 2.5 kWh/d could be used for household needs; therefore, it is calculated as electricity saving.

Increase in the comfort level is achieved by using cooling ceilings. The lifetime of these elements exceeds 20 years. Therefore, the relevant costs could be added to the investments in conventional air conditioning.

Maintenance costs are 1 695 Euro in 20 years of PV-SAC operation. The expected gain of electricity overproduction is 4 326 Euro in the same time period.

For comparison, the initial investment in CAC is 1 200 Euro, and in cooling ceiling it is 2 560 Euro including installation. The total investment in CAC (maintenance included) is 19 400 Euro in 20 years. Therefore, the profit of 3 767 Euro using the PV-SAC technology could be obtained by its substitution for the conventional air conditioning and heating technology (CAC&H). The ARR is here:

$$ARR_{20} = \frac{21\,472}{17\,705} = 121.3\ \%\ .$$

Figure 2 shows that investment and maintenance costs of conventional technology will exceed the costs of PV-SAC technology in 15 years. The jumps of the curves show periodical replacement of system parts. Thence, the estimated payback time seen in Fig. 2 is 15 years.

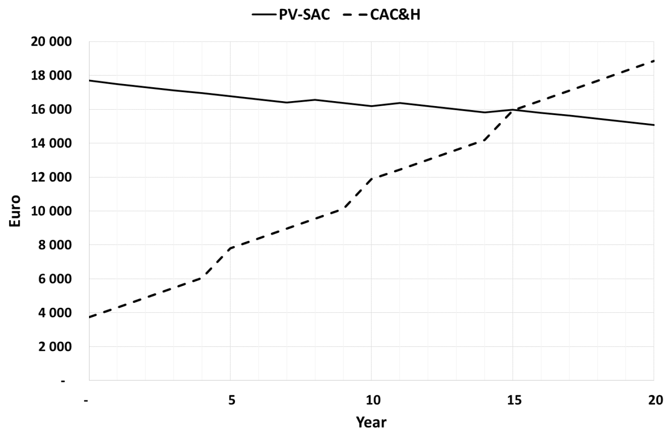


Fig. 2. Initial investment and maintenance costs of PV-SAC and CAC&H technologies.

The costs of electricity, heat, and equipment replacement are exposed to inflation. Hence, the inflation would increase the revenue of PV-SAC in the future. Possibility of alternative investments decreases the value of future revenue, in which case bank deposit interests could be of help. The deposit interest rate is from 1 % up to 5 %, and the annual inflation is usually up to 4 %. Respectively, the discount rate could be from -3 % to +5 % in a long-term projected future.

Table 1

Net Present Value (NPV) Determination during the PV-SAC System Lifetime

	Discount rate					
	5 %	3 %	1 %	0 %	-1 %	-3 %
Initial costs	13 945	13 945	13 945	13 945	13 945	13 945
NPV, Euro (€)	-2 905	-797	1 948	3 633	5 577	10 444

The PV-SAC revenue seen in Table 1 shows comparative savings of maintenance costs for PV-SAC and CAC&H systems. Initial costs include savings obtained by PV-SAC installation instead of CAC&H. The cost of cooling ceiling installation is not included in the initial cost due to the previously mentioned reason. The results of research indicate that investment in PV-SAC technology is worth doing at the discount rate up to 2.36 %. Besides, the payback time is extended by increasing the discount rate.

The PV-SAC provides electricity for its own needs, e.g., for cold generation at the peak cooling consumption. Hence, additional benefit of PV-SAC technology is the utilisation of electricity reserves. The price of long-term electricity reserves is 30 Euro/MWh [4] up to 80 Euro/MWh [5]. The long-term simulation shows that the peak cooling demand is lasting for several weeks a year. Respectively, extra 672 Euro per reference system is saved by utilisation of electricity reserves.

4. ENVIRONMENTAL IMPACT

Energy generation and conversion always include environmental impacts. The use of PV-SAC technology promotes environment-friendly energy generation. Solar energy is renewable, clean, and predictable energy source, so it helps protect environment. Solar energy does not release carbon dioxide (CO_2), nitrogen oxides, sulfur dioxide, mercury, etc. into the atmosphere as is done using many of conventional heat and electricity sources. Not polluting the air, solar energy does not contribute to global warming, acid rains or smog.

The CO_2 content of atmosphere is one of the parameters for revealing the environmental impact of technology use. The potential of CO_2 reduction takes into account the CO_2 emission factor of the energy used. Therefore, substitution of solar energy for CO_2 producing (e.g., fossil) electricity sources reduces its emission into the air, thus reducing global warming.

The world total emission is 35.67 Gton per year [6] in CO_2 equivalent. Trends of global emission show that nowadays CO_2 emission is 23 % higher than 10 years ago, and 55 % higher than 20 years ago. Electricity and heat production emits 25 % [7] of global greenhouse gas (GHG) emission. Therefore, the reduction of such emissions is one of the main targets of the leading projects of environmental protection.

The estimates of carbon dioxide emissions from the energy sector are based on the methodology worked out by Intergovernmental Panel on Climate Change (IPCC). The European emission factor for the consumed electricity (EF_{el}) is 460 kg/MWh [8].

The CO_2 calculation assumes that for heat generation the natural gas with density (ρ_{NG}) of 0.717 kg/m^3 is used. The molecular weight of carbon dioxide (MW_{CO2}) is 44.0098, g/mcl, and of carbon (MW_C) – 12.011 g/mcl. The carbon content of the fuel (i.e., natural gas) is assumed to be 74.2 %. Lower calorific value of natural gas (LCV_{NG}) is 13.09 kWh/kg. Consequently, the emission factor of stationary combustion heat is 208.86 kg of CO_2/MWh. This factor decreases to EF_{NG} = 207.82 kg of CO_2/MWh by taking into account the CO_2 oxidation factor.

The PV array generation is 2.344 MWh/a, with an amount of electricity consumed for cold and heat generation and the rest fed into the grid. Overproduction of electricity is 1.04 MWh/a. Conventional air conditioning consumes 1.652 MWh/a of electricity for the same amount of cold generation. The auxiliary heat source in the CAC&H system consumes 219 kg/a of natural gas for heat generation equivalent to the evaluated technology. Respectively, the reduction in global GHG emission is 1 835 kg of CO_2 per year.

5. CONCLUSION

Solar energy – as a renewable energy source – is available at the same time as room cooling is needed, and in this case a SAC system is a reasonable alternative to the systems using fossil fuel. As previously mentioned, the PV-SAC technology decreases CO_2 emission, at the same time increasing the comfort level in living rooms.

It is possible to integrate PV-SAC technology in the common HVAC engineering field. Currently, the PV electricity driven solar air conditioning systems are unavailable on the market, so no experience exists as to running such type of systems, despite the commercial availability of all PV-SAC components.

The investments and maintenance costs of conventional SAC technologies are expected to exceed those of PV-SAC technology in 15 years. Investment in the PV-SAC technology is worth doing at a discount rate up to 2.36 %.

REFERENCES

1. Snegirjovs, A., Gantenbein, P., Omlin, L., and Shipkovs, P. (2015). Improved model of combined PV solar cooling and free cooling system. *6th International Conference on Solar Air-Conditioning*, 162–167. Regensburg, Germany: OTTI.
2. *Statistical information centre – Eurostat*. Available at www.ec.europa.eu/ eurostat
3. Truong, N. L., and Gustavsson, L. (2014). Cost and primary energy efficiency of small-scale district heating systems. *Applied Energy, 130*, 419–427.
4. Hummon, M., Denholm, P., and Jorgenson J. (2013). Fundamental Drivers of the Cost and Price of Operating Reserves. Denver, USA: National Renewable Energy Laboratory.
5. Just, S, and Weber, C. (2008). Pricing of reserves: Valuing system reserve capacity against spot prices in electricity markets. *Energy Economics, 30*, 3198–221.
6. *The Emissions Database for Global Atmospheric Research*. Available at www.edgar.jrc.ec. europa.eu
7. Ban-Weiss, G. (2013). Electricity production and cooling energy savings from installation of a building-integrated photovoltaic roof on an office building. *Energy and Buildings, 56*, 210–220.
8. Covenant of Mayors. (2015). *The Emission Factors*. Technical document. Geneva, Switzerland: The Intergovernmental Panel on Climate Change.

FOTOELEKTRISKĀS SAULES ENERĢIJAS GAISA KONDICIONĒŠANĀS DARBĪBAS NOVĒRTĒJUMS

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K o p s a v i l k u m s

Pieejamā informācija par elektriski darbināmām saules enerģijas gaisa kondicionēšanas sistēmām (SAC) ir ierobežota. Ievērojams skaits tehnisko datu galvenokārt attiecas uz liela mēroga fotoelektriskajām saules gaisa kondicionēšanas sistēmām. Ticama informācija par šādu sistēmu saražotās enerģijas apjomu ir noskaidrota tikai pēdējo gadu laikā, taču tā bieži vien nav publiski pieejama, kaut arī ir liela saules enerģijas pētnieku un inženieru interese par šāda veida SAC sistēmām. Šajā pētījumā tiek analizēta PV-SAC tehnoloģija, kurā izmantota mazjaudas sistēmas (ar vidējo dzesēšanas jaudu līdz 15 kWp), darbības novērtējums. Šāda sistēma ietver

PV elektriski darbināmu kompresijas dzesētāju ar aukstuma un siltuma enerģijas uzkrājējiem un siltumenerģijas novadīšanu karstā ūdens vajadzībām. Ne-dzesēšanas sezonā ir iespējams izmantot šo sistēmu apgrieztā režīmā. Šajā režīmā apkārtējais gaiss kalpo kā siltuma avots. Turklāt «brīvā dzesēšana» ir paredzēta PV-SAC sistēmas koncepcijā.

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LIFECYCLE ANALYSIS OF DIFFERENT MOTORS FROM THE STANDPOINT OF ENVIRONMENTAL IMPACT

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Comparative analysis is performed for different motors from the standpoint of damage inflicted by them during their lifecycle. Three types of motors have been considered: the synchronous reluctance motor, the permanent magnet assisted synchronous reluctance motor and the induction motor. The assessment of lifecycle has been made in terms of its four stages: manufacturing, distribution, use and end of life. The results show that the production costs of synchronous reluctance motor are lower compared to that of permanent magnet assisted motors, but due to their low efficiency they exert the greatest environmental impact. The main conclusion is that the assessment made at the early designing stage for the related environmental impact enables its reduction.

Keywords**:** environmental impact, induction motor, lifecycle assessment, permanent magnets, synchronous reluctance motor.

1. INTRODUCTION

Electric motors consume 43 %–46 % of global electricity, which means about 6040 Mt CO_2 emissions per year [1]. In this paper, an electric motor is defined as a device that converts electric energy into mechanical energy. As part of the coordinated efforts throughout the world to reduce the energy consumption and CO_2 emissions the regulation authorities in many EU countries have introduced the ICE 60034-30-1:2014 regulation to stimulate the production and use of high-efficiency motors [2]. Toughening the energy efficiency requirements leads to the search and development of alternative technologies for electric motors. However, the manufacturing of diversified products and services causes the ecological crisis. During their entire lifecycle, these products contribute repeatedly to the environmental pollution. Nowadays, improving the efficiency of the electric motor goes on concurrently with a decrease of harmful emissions arising at the phases of production, use, and disposal. Therefore, a topical issue is the product lifecycle assessment (LCA), whose main principles are defined by the International Organisation for Standardisation: ISO 14040 and ISO14044 standards [3], [4]. The former (ISO 14040 standard) presents the introduction into the LCA and describes its applicable specifications, containing also the reference information, while the latter (ISO 14044 standard) regulates the LCA performance process.

2. LIFECYCLE ASSESSMENT

The lifecycle assessment implies important procedures that can help reduce motor impact on the environment, thus being an instrument for assessment of the influence exerted by particular products on the environment – from cradle to grave – beginning with acquisition of the materials followed by manufacturing, transporting, marketing, use and recycling. Similar to other products, in the motor lifecycle four stages could be distinguished (see Fig. 1).

Fig. 1. Four stages in the product lifecycle.

The **production** stage. Pollution of the environment begins with extraction of natural resources. Therefore, the first stage includes the extraction of natural resources and energy sources from the Earth. Transportation of the basic material prior to its processing also belongs to this stage, followed by the processing of the raw material and obtaining of the final product. For the production of electric machines, the following materials are used: winding electrical copper, sheet steel, impregnating varnishes and compounds, cover enamels, as well as widely diversified materials of the electrical insulation (paper, cardboard, polyester films and ribbons, stratified plastics, plastic material, mica, asbestos). To produce an electric motor, the general machine industry technological processes are applied. Figure 2 shows a block diagram of producing of electric machine.

The **distribution** stage includes all technological processes needed for packing and transportation of the final product. The energy and ecological waste caused by transportation to the shopping units or to the customer are taken into account within this stage of lifecycle.

The **use** stage is the longest and the most expensive stage within the lifecycle of an electric machine. This stage is mostly associated with the customer: the actual use, the repeated use, and the service life of the product. The energy needs and ecological waste are included in the use stage due to storage and consumption. At this stage, the operational efficiency of electric motor is especially important. The main parameters of a motor are its output power and efficiency. Therefore, it should be properly designed not only because of economic reasons, but also due to ecological aspects. The electric motors are generally designed for the lifespan of 15–20 years without overhaul under the condition of their normal operation. At the use stage, pollution is mainly caused by overheat, generation of external magnetic fields, noise, vibration, emissions of volatile substances from electrical materials. It should be noted that when the power of the electric machine is higher, the values of these polluting parameters are also higher [7]. The use stage of MEEUP model also includes trips for repair and maintenance as the distance covered over the motor life (250 km).

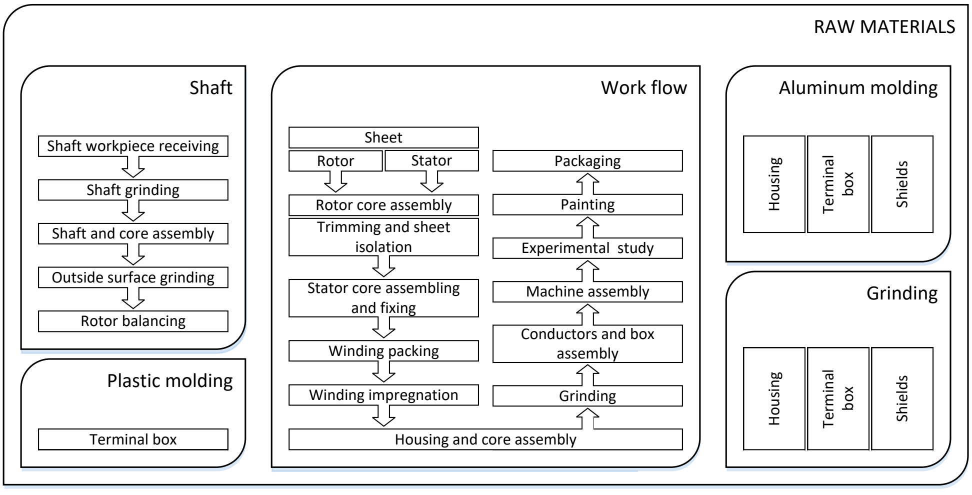

Fig. 2. Block diagram of manufacturing of the electric machine.

End of life means that the state of an electrical machine has reached the end of its first use until its final disposal. The end of life stage includes the energy needed for recycling the product as well as waste recycling, composting and burning in compliance with the relevant regulation.

The main reasons for making LCA are as follows:

- willingness to collect the information about the ecological influence of the product or service in order to find the possibilities to reduce the environmental impact;
- necessity to explain to the consumer the best methods of application of the product and its recycling;
- collection of the information on the receipt of eco-certificates;
- comparison of the environmental impact made by different products.

3. RESULTS OF THE COMPARATIVE ANALYSIS AND DISCUSSION

The comparison was performed in view of the related environmental impact. For its assessment many methodological approaches have been developed (Table 1) [8], [9]. In the present research, the Methodology for the Ecodesign of Energy-using Products (MEEuP) is applied, which has been worked out to determine whether and to what extent a product meets the criteria stipulated in the Directive on the Ecodesign of Energy-using Products (EuP 2005/32/EC) [5].

The MEEuP analysis requires these inputs [10]:

- bill of materials and manufacturing processes;
- performance, consumption and emission characteristics during the use phase;
- distribution characteristics: volume of package final product, transport mix;
- end-of-life characteristics: recycling and waste disposal.

Table 1

The List of Methodologies for LCA

Methodology	Developed by	Country of origin
CML 2002	CML	The Netherlands
Eco-indicator 99	PRé	The Netherlands
EDIP97-EDIP2003	DTU	Denmark
EPS 2000	IVL	Sweden
Impact 2002+	EPFL	Switzerland
LIME	AIST	Japan
LUCAS	CIRAIG	Canada
ReCiPe	RUN+ PRé+CML+RIVM	The Netherlands
Swiss Ecoscarcity 07	E2+ESU-services	Switzerland
TRACI	US EPA	The USA
MEEuP	VhK	The Netherlands

The MEEuP methodology provides a tool for estimation of the environment impact. At the preparatory phase, the economic, material and energy use data were collected for inputting to a relevant model at different stages of a product lifecycle. The model translates these inputs into quantifiable environmental impacts.

The results of MEEuP analysis are presented as a list of environmental indicators [10]:

- energy, water (process and cooling);
- waste (hazardous and non-hazardous);
- global warming potential (GWP);
- acidification potential;
- volatile organic compounds (VOCs);
- persistent organic pollutants (POPs);
- heavy metals (to air and water);
- polycyclic aromatic hydrocarbons (PAH);
- particulate matter (PM);
- eutrophication potential of certain emissions to water (EP);
- ozone depletion potential.

In the present research, the lifecycle assessment has been performed for three types of motors: synchronous reluctance motor (SynRM), permanent magnet assisted synchronous reluctance motor (PMSynRM), and induction motor (IM).

Table 2 presents the materials used for motor manufacturing obtained by using geometric modelling of the reference motors. The motors of the 1st and 2nd type are similar in design, with the only difference that PMSynRMs have high-energy permanent magnets in the rotor air barriers. It should be noted that the available permanent magnets make the design heavier and much more expensive. The input data on induction motors are taken from the EuP base case [6]. The major materials used for electric motors (e.g., steel, aluminium, copper) are recyclable and have a very high value; therefore, they are recycled at the end of life.

Table 2

Bill of Materials for Motor Production

Material	Weight (kg)		
	SynRM	PMSynRM	IM
Electrical steel	34.900	34.900	36
Other steel	2.110	2.110	9.500
Aluminium	12.764	12.764	13
Copper	6.546	6.546	6.400
Insulation material	0.200	0.200	0.200
Permanent magnets	-	0.710	-
Impregnation resin	0.470	0.470	1
Paint	0.302	0.302	0.500
Packing material	9	9	9

Some design recommendations can be made to improve the environmental impact of electric motors, namely [6]:

- motors should be easily assembled and disassembled;
- a reduction of the diversity of materials used should be sought;
- a reduction of non-recyclable parts, namely plastic, should be sought;
- windings should be easily removed.

Table 3 presents the parameters important for the use stage: the lifetime of a motor (taken 15 years), its operating hours, efficiency, and output power.

Table 3

Parameters Important for the Use Stage of Motors

Parameter	Value		
	SynRM	PMSynRM	IM
Lifetime (years)	15	15	15
Operating hours	3000	3000	3000
Efficiency (%)	70	90	87.6
Output power (kW)	10	10	10

Table 4 presents the indicators of the environmental impact made by the motors (lifetime 15 years, operation 3000 h) during their lifecycle. The lifecycle indicators are divided into three blocks: main indicators, emissions into air and emissions into water.

Table 4

Lifecycle Indicators of the Environmental Impact Made by the Motors

Main indicators	SynRM	PMSynRM	IM
Total energy GER(1) (MJ)	677 883	531 180	546 584
of which, electricity (in primary MJ)	673 562	526 625	541 570
Water process (ltr)	47 740	37 972	38 894
Water cooling (ltr)	1 793 733	1 401 174	1 439 963
Waste, non-hazardous landfill (g)	961 094	792 773	838 025
Waste, hazardous incineration (g)	15 967	12 582	13 388

Emissions into air	SynRM	PMSynRM	IM
Greenhouse gases in GWO 100(2) (kg CO_2 eq.)	29 746	23 349	24 032
Acidification, emissions (g SO_2 eq.)	177 857	140 064	144 359
Volatile organic compounds (g)	262	210	217
Persistent organic pollutants (POP)	5 455	4 522	4 886
Heavy metals (mg Ni eq.)	23 598	21 112	25 216
PAHs (mg Ni eq.)	1 590	1 306	1 344
Particulate matter (g)	4 488	4 172	4 362

Emissions into water	SynRM	PMSynRM	IM
Heavy metals (mg Hg/20)	7 730	6 784	6 883
Eutrophication (g PO4)	146	142	165

(1) Gross energy requirement
(2) Global warming potential

It should be noted that in Table 4 a loss-based environmental impact analysis is presented; in this paper an electric motor is defined as an energy converter (not as an end-use device).

In Fig. 3, greenhouse gas exemplary curves are shown. Greenhouse gases are those that absorb and emit infrared radiation at the wavelengths emitted by the Earth. More information about emissions taken into account in this paper is given in the Appendix.

As follows from Table 5, the use stage completely dominates over the life-cycle impact of electric motors; it is directly dependent on the efficiency of the designed motor. This stage involves many processes from the ecological and economic points of view.

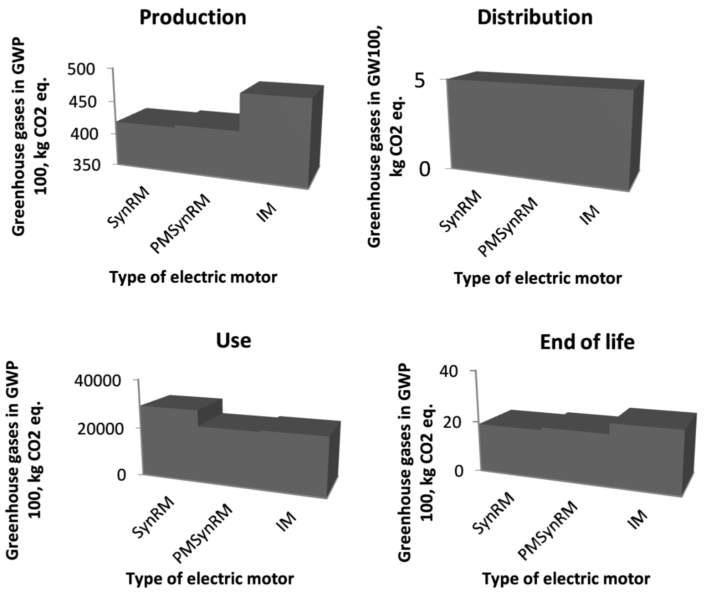

Fig. 3. Greenhouse gases *vs*. the type of electric motor at four lifecycle stages.

At the distribution stage, the MEEuP model assumes a distance of 200 km for the first trip from manufacturer (or retailer) to the installation site [6], but not the distance covered by trips for repair and maintenance of the motor.

Table 5

Environmental Impact Made by the Motors at Different Lifecycle Stages

Type of motor	Production, %	Distribution, %	Use, %	End of Life, %
SynRM	1.404	0.017	98.515	0.064
PMSynRM	1.807	0.21	98.086	0.086
IM	1.980	0.21	97.9	0.100

5. CONCLUSION

From the four stages of the motor lifecycle described above, the production stage is less costly for the synchronous reluctance motor, as there are no high-energy magnets and the rotor is without winding. Respectively, the raw materials used in production are cheaper and less influential for environment. However, this type of motor produces a huge amount of waste during the use stage due to its low efficiency. Motors with low efficiency have high utilisation costs and high emissions in the environment. As far as the PMSynRM is concerned, it should be noted that, although the use of permanent magnets makes this design expensive and heavy, still in their operation this type of motors inflicts little damage to the environment during the usage phase.

Based on the results of the comparative analysis, the conclusions are as follows.

1. The LCA allows comparing different products and determing which of them is more environmentally friendly not only during the production phase, but also taking into account the entire lifecycle period.
2. In the future, it is not possible to produce the product without being aware of the product impact on the environment. The producers should know what happens before and after the production stage at a factory.
3. The assessment of the expected environmental impact should be performed at the early design stage, which would allow decreasing the harmful emissions into the atmosphere.
4. The PMSynRMs are the most expensive motors in terms of production, while at the use stage they exert little environmental impact.

ACKNOWLEDGEMENTS

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REFERENCES

1. Waide, P., and Brunner, C. U. (2011). *Energy-Efficiency Policy Opportunities for Electric Motor-Driven Systems*. Working paper. International Energy Agency. Energy Efficiency Series.
2. IEC. (2014). *IEC 60034-30-1:2014: Rotating Electrical Machines* – Part 30-1: Efficiency classes of line operated AC motors (IE code). p. 50 .
3. ISO. (2006). *ISO 14040:2006 – Environmental Management*: Life cycle assessment. Principles and framework. p. 20.
4. ISO. (2006). *ISO 14044:2006 – Environmental Management*: Life cycle assessment. Requirements and guidelines. p. 46.
5. *EuP Network Website*. [Online]. Available at http://www.eup-network.de/updates/
6. de Almeida, A. T., Ferreira, F. J. T. E., Fong, J., and Fonseca, P. (2008). *EUP Lot 11 Motors*. Coimbra.
7. Vaimann, T., Kallaste, A., Kilk, A., and Belahcen, A. (2013). Lifecycle-based design and optimization of electrical motor-drives: Challenges and possibilities. In *3rd International Conference on Electric Power and Energy Conversion Systems* (pp. 2–5).
8. Lehtinen, H., Saarentaus, A., Rouhiainen, J., Pitts, M., and Azapagic, A. (2011). *A Review of LCA Methods and Tools and their Suitability for SMEs List of Contents*. [Online]. Available at http://www.biochem-project.eu/download/toolbox/sustainability/01/120321%20BIOCHEM%20LCA_review.pdf
9. Williams, A. S. (2009). *Life Cycle Analysis: A Step by Step Approach*. ISTC Reports. Illinois.
10. Andrada, P., Blanqué, B., Martínez, E., Perat, J. I., Sánchez, J. A., and Torrent, M. (2012). Environmental and life cycle cost analysis of one switched reluctance motor drive and two inverter-fed induction motor drives. *IET Electric Power Applications 6* (7): 390–398.

Greenhouse gases (GHGs): a group of gasiform compounds, which are components of the Earth atmosphere. They practically do not pass through the thermal radiation coming from our planet. The following compounds are included into the GHG list: water vapour, carbon dioxide (CO_2), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFC), sulphur hexafluoride (SF_6).

Acidification: caused mainly by emitting the oxidizing substances – ammonia (NH_3), sulphur oxide (SO_2), and nitrogen (N). The emissions of the acidifying substances cause serious damage to the environment and humans.

Volatile Organic Compounds (VOCs): the chemical substances emitted to the atmosphere, in combination with nitrogen oxide (NO) and ozone (O_3). These are chemical substances whose initial boiling point measured at the standard pressure is 101. 3 kPa or 250 ^oC.

Persistent Organic Pollutants (POPs) are the primary or by-products of the industry. Nowadays, 12 substances are designated as POP: polychlorinated biphenyls ($C_{12}H_4Cl_4O_2$) and furans (C_4H_4O), polychloride biphenyls ($C_{12}H_{10-n}Cl_n$), DDT($C_{14}H_9Cl_5$), chlordan ($C_{10}H_6Cl_8$), heptachlor ($C_{10}H_5Cl_7$), hexachlorbenzene (C_6Cl_6), toxaphene ($C_{10}Cl_{12}$), aldrin ($C_{12}H_8Cl_6$), dieldrin ($C_{12}H_8Cl_6O$), endrinimirex. As a rule, the POPs have common characteristics: they are low-volatile chemically stable compounds, which are able to remain in the environment for a long time without being decomposed.

Heavy metals and their compounds stand out within the various polluting substances by prevalence, high toxicity, many of them also by the ability to bioaccumulation. They are widely used in various industries, so despite the clean-up procedures the content of heavy metals in the industrial wastewater is rather high. They also enter the environment from the domestic wastewater, smoke and dust of industrial enterprises.

Polycyclic aromatic hydrocarbons (PAHs) are high molecular weight organic compounds of the benzene series, differing in the number of benzene rings (2 to 7). The technology-related PAHs are formed during the combustion of fossil fuels in the industry and energy economy when producing coke or operating the internal combustion engine.

Eutrophication is the saturation of water reservoirs with biogenic elements, accompanying the increase in the biological productivity of water reservoirs. The eutrophication can be a natural result of the aging of the reservoir, as well as due to anthropogenic impacts. The main chemical elements contributing to the eutrophication are phosphorus (P) and nitrogen (N).

DZĪVES CIKLA ANALĪZE DAŽĀDIEM DZINĒJIEM NO IETEKMES UZ VIDI VIEDOKĻA

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K o p s a v i l k u m s

Dzīves cikla salīdzinājuma analīze tiek veikta dažādiem dzinējiem no to kaitīgās ietekmes uz vidi viedokļa. Tiek apskatīti trīs ģeneratora tipi: sinhronais reaktīvais dzinējs, sinhronais reaktīvais dzinējs ar pastāvīgajiem magnētiem un asinhronais dzinējs. Dzīves cikla analīze tiek izpildīta četriem etapiem: izgatavošana, sadale, izmantošana un dzīves beigas. Rezultāti parāda, ka sinhronais reaktīvais dzinējs ir lētāks izgatavošanā, nekā dzinējs ar pastāvīgajiem magnētiem, bet, pateicoties zemajam lietderības koeficientam, kaitīgāk ietekmē vidi. Galvenais secinājums ir tāds, ka dzīves cikla novērtējums ir jāveic agrā projektēšanas stadijā, lai samazinātu ietekmi uz vidi

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ELECTRICITY MARKET LIBERALISATION AND FLEXIBILITY OF CONVENTIONAL GENERATION TO BALANCE INTERMITTENT RENEWABLE ENERGY – IS IT POSSIBLE TO STAY COMPETITIVE?

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Intermittent generation (solar PV and wind energy) integration in power production portfolio as well as electricity price fluctuations have changed the running manner of conventional combined heat and power (CHP) plants: the shift from base load operation to running in cyclic modes. These cogeneration power plants are not adapted to new running conditions. The level of CHP plant flexibility should be improved to operate profitably and efficiently from both technical and fuel usage point of view. There are different ways to increase the flexibility of power plants. Before any improvements, the situation at power plants should be evaluated and the weakest points defined. In this publication, such measures are presented on Riga CHP-2 plant example: installation of heat storage tank; extension of operation rang; acceleration of start-ups.

Keywords: *electricity price fluctuation, flexibility, intermittent generation.*

1. INTRODUCTION

The running conditions of cogeneration power plants have changed from base load operation to running conditions in cyclic modes due to implementation of market mechanisms, feed-in tariffs for renewable energy sources (RES) and large-scale integration of RES in energy production process [1], [2]. As an example, the changes in Riga CHP-2 plant generation profile are reflected in Figs. 1 and 2.

The base load power plants are not accommodated to such running conditions. That is why CHP plant operation is inefficient from technical and fuel usage point of view without flexibility level improvement. It results in additional costs and reduction of gains. There are two solutions: (1) to mothball power plants or (2) to keep on operation after implementation of appropriate measures. The second option is more logical than the first one, taking into account the benefits of cogeneration power plants and the forecasted increase of them [1]. Moreover, it is impossible to ensure the secure energy supply and provide the successful integration of intermittent renewable energy in energy production process without CHP plants [3].

There are plenty of various solutions (measures) to enhance the flexibility of base load power plants. The measures concerning cogeneration power plants at the *operation stage* are going to be presented. They were divided into five groups by the authors in [1]: (1) equipment upgrade; (2) storage opportunities; (3) operation optimisation; (4) new installations; and (5) competitiveness increase.

In the present research, Riga CHP-2 plant is used as an example, when proper measures are introduced with the aim to ensure profitable operation of cogeneration power plants in cyclic modes. The already implemented solution and measures under investigation are going to be reflected. The paper is organised as follows: in Section 2 the aspects of new running conditions are presented; in Section 3 the description of the investigated object is provided; in Section 4 the already implemented measure is presented; in Section 5 the measures under investigation are reflected; in Section 6 the main conclusions are made.

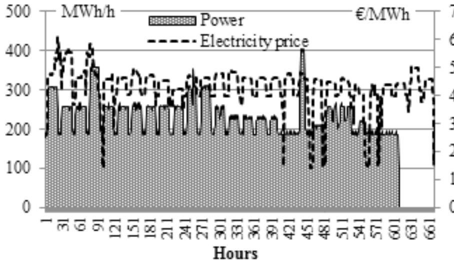


Fig. 1. Electricity generation profile of Riga CHP-2 plant from 01.02.2013 to 28.02.2013.

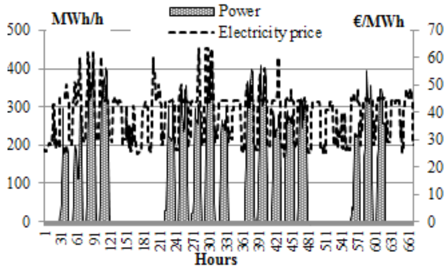


Fig. 2. Electricity generation profile of Riga CHP-2 from 01.02.2015 to 28.02.2015.

2. CYCLIC OPERATION: REASONS, AIMS AND BENEFITS

The cyclic operation means operation with frequent unit load reduction or its full stop, when energy fluctuation takes place or price of electricity is low [4]. Aspects of cyclic operation like reason-(s), aim-(s) and benefits vary according to the situation of energy system in a region. The comparison of the situation in Latvia and Germany is presented in Table 1.

Table 1

The Comparison of Situation in Latvia and Germany

Parameters	Latvia	Germany
Reasons of cyclic operation	The fluctuations of electricity price in Nord Pool market	Intermittency of renewable energy sources
Aims of flexibility increase	Adjustment to the situation in Nord Pool market	Integration of intermittent generation in energy production process
Benefits of flexible operation	Obtaining additional profit, when electricity price is high. Ensuring profitable operation of the existing power plants	Secure integration of intermittent generation in use. Opportunity to be *"the quickest"* and offer *"the first megawatts"*

Latvia does not have a plenty of intermittent generation sources. Cyclic operation became common after Latvia had joined Nord Pool market. It happened on June 3, 2013. Now fluctuations of electricity price determine the operation of power plants [4]. In contrast, in Germany the main reason of CHP plant cyclic operation is an availability of renewable energy generation (solar PV and wind energy). The flexible cogeneration power plants provide a more secure integration of renewable energy sources in energy production process. Moreover, in Germany CHP plants participate in frequency control that is why the competition between power plants increases. It is important "*to be the first and offer the first megawatts*" [5].

As of today, the provision of regulation service to the transmission system operator is not so common for CHP plants in Latvia like it is in Germany. Firstly, Latvia is part of BRELL (Belarus, Russia, Estonia, Latvia and Lithuania) power ring and the primary regulation is provided by Russian hydropower plants. Secondly, there is a cascade of Daugava hydropower plants in Latvia and Kruonis pumped storage plant in Lithuania, which are used to regulate frequency due to their ability of fast response to changes in the energy system.

3. DESCRIPTION OF RIGA CHP-2 PLANT

Riga CHP-2 plant is one of the most up-to-date power plants in Europe. It is located in Riga, Latvia. Power plant consists of two cogeneration units: Riga CHP-2/1 and Riga CHP-2/2 and a water heating boiler house. The thermal capacity of CHP-2/1 is 274 MW and electrical power – 413 MW (442 MW in condensing mode). The thermal capacity of CHP-2/2 is 270 MW and electricity power – 419 MW (439 MW in condensing mode). The water heating boiler house has five natural gas fired heat-only boilers (HOBs) (5×116 MW). Thus, the total thermal capacity of the water heating boiler house is 580 MW. Natural gas is used as primary fuel, and diesel is used as emergency fuel at Riga CHP plants [4], [6].

Riga CHP-2 plant was constructed as a based load power plant. However, now it should operate in cyclic modes since the end of 2013 (Fig. 2). That is why the flexibility level of Riga CHP-2 plant should be incremented. It should correspond to the requirements of cyclic operation, i.e., fast start-up and ramp rate; extended turndown [7]. For these reasons, the modernisation (technical minimum reduction) of gas turbine is completed at Riga CHP-2/2 (Section 4). There are also solutions under investigation: installation of heat storage system and acceleration of start-ups (see Section 5).

4. GAS TURBINE MODERNISATION OR MINIMUM TECHNICAL REDUCTION OF COGENERATION UNIT

OpFlex Turndown upgrade allows a gas turbine to operate at lower loads, maintaining stable combustion and emission compliance. This enhances power plant electricity dispatch priority, reduces number of start-ups and fuel consumption [8].

Gas turbine of Riga CHP-2/2 was equipped with *OpFlex Turndown* in 2014. The benefits of this modernisation: (1) the prevention of cogeneration unit from daily start-ups (the number of allowed start-ups is limited and it is a function from operating hours); (2) the deep unloading of unit at night, when electricity price is low. Simplified analysis (at the price of natural gas – 345.65 €/1000m^3 and CO_2 – 7 €/t) of four possible running conditions of Riga CHP-2/2 was carried out to evaluate upgrade. As a result, the marginal costs of electricity production (consumed fuel and produced emissions) are as follows:

- Mode No. 1 (operation of cogeneration unit at base load) – 246.79 thous. €;
- Mode No. 2 (cogeneration unit is not in operation and electricity is purchased at Nord Pool power exchange for 24 hours) – 245.30 thous. €;
- Mode No. 3 (operation of cogeneration unit in cyclic mode with shut-down at night) – 230.34 thous. €;
- Mode No. 4 (load reduction of cogeneration unit at night by implementing *OpFlex Turndown* solution) – 243.92 thous. €.

In condition of cyclic operation, it is not profitably and reasonably to operate a cogeneration unit at base load (Mode No. 1) or mothball it and buy electricity on the electricity market (Mode No. 2), because the costs of Mode No. 1 and Mode No. 2 are the highest ones. It is beneficial to shut-down cogeneration unit (Mode No. 3). However, owners of Riga CHP-2 plant are not interested in stopping the unit every day due to adverse affect of start-up procedure [4], the cogeneration unit is not adapted to operate in cyclic running conditions and the number of start-ups is limited. That is why the installation of *OpFlex Turndown* solution was the first step towards the improvement of Riga CHP-2 flexibility and efficiency (Mode No. 4).

5. MEASURES UNDER INVESTIGATION

5.1. Heat Storage Tank Installation – Adjustment to Variations of Electricity Price

One of the most efficient ways of increasing the flexibility of cogeneration power plants is to decouple the production of electricity and heat energy. It can be done by installing a heat storage system. Two examples of already implemented projects and proposals of Riga CHP-2 plant project are provided in Table 2.

Table 2

Comparison of Heat Energy Storage System Projects

Parameters	***GKM* CHP plant, Germany [9]**	***Sandreuth* CHP plant, Germany [5]**	**Riga CHP-2 plant, Latvia *(proposals)***
Aim	Adjustment to electricity price variations	Integration of RES and regulation service provision to transmission system operator	Adjustment to electricity price variations; increase in efficiency and competitiveness.
Benefits	Minimum technical reduction; Operation of one unit, when load is minimum	Secure RES integration; Ability to competitiveness	Stay in operation; Additional profit; Reduction of fuel used and produced emissions
Volume, m^3	43 000	33 000	20 000
High, m; Diameter, m	H = 36 m; D = 40 m	H = 70 m; D = 26 m	H/D=1.5* (H/D~0.4)**
Investments, M€***	27	12.4	10.6* (8.5)**

*correspond to a new tank; ** correspond to a heavy fuel oil tank; *** million €

The installation of heat storage tank at Riga CHP-2 is under investigation. The tank volume 20 000 m^3 was chosen. This volume ensures two options: installation of a new heat storage tank or reconstruction of the existing heavy fuel oil tank as a heat storage tank. They are compared in Table 3.

Table 3

Installation of New Heat Storage Tank or Reconstruction of Existing Heavy Fuel Oil Tank

Parameters	**New heat storage tank**	**Reconstructed heavy fuel oil tank**
Construction	Construction according to standard requirements	Inspection of construction
Type and volume of heat storage tank	Choice of tank type and volume	Adjustment to tank type and volume
Height and diameter ratio (H/D)	Choice of optimal H/D. Secure use of heat storage tank	H/D ~ 0.4. Investigation of internal process (stratification, pressure, etc.)
Installation	Opportunity to choose the site of installation	The installation site is already known
Connection to the system	Flexible connection to the system	According to the existing site condition
Investment	High investments	Equal to reconstruction costs
Additional works	Construction works	Cleaning from heavy fuel oil and its utilisation

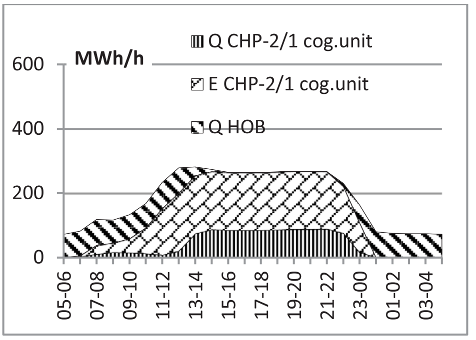
The benefits of project are evaluated taken into account four components: difference between additionally produced and purchased electricity (ΔP_{el}); difference between additionally consumed and saved natural gas ($\Delta B_{nat\ gas}$); difference between additionally produced and reduced CO_2 emissions (ΔE_{CO_2}); effect of start-up process ($Start\text{–}up_{effect}$), e.g., used fuel and produced CO_2 emissions:

$$Benefits = \Delta P_{el} + \Delta B_{nat\_gas} + \Delta E_{CO_2} + Start\text{–}up_{effect}.$$

Eight typical days were chosen to calculate the benefits: three for a non-heating period and five for a heating period. The example (at the price of natural gas – 196.25 €/1000m^3 and CO_2 – 7 €/t) of one typical day from a non-heating period is provided in Figs. 3 and 4. The cogeneration unit is shut-down during the night time, when the electricity price is low. Thus, the heat energy is provided by heat-only boilers and electricity is purchased (Fig. 3).

The installation of heat storage tank improves the efficiency of cogeneration unit and adjusts its running conditions to a situation in the electricity market: increase of electrical and heat load during the day time, when the electricity price is high. Additionally produced electricity is sold and heat energy is accumulated for further use by replacing the production of heat-only boilers at night (Fig. 4).

To produce additional electricity (Fig. 5) and heat during the day time, more natural gas is consumed (Fig. 6). The gain from produced electricity (18 602 €/24 h) exceeds the costs of natural gas (3 980 €/24 h) and CO_2 emissions (264 €/24 h). Thus, the additional profit is 14.4 thousand € per day.



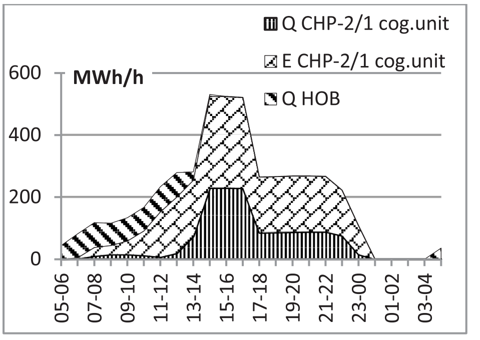
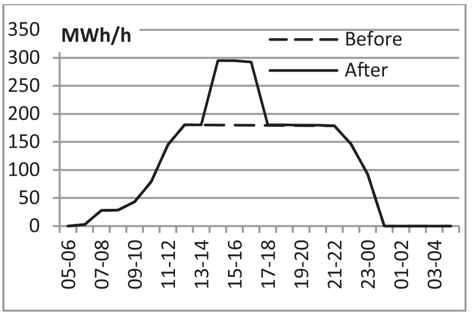


Fig. 3. Operation of Riga CHP-2/1 before the heat storage system implementation.

Fig. 4. Operation of Riga CHP-2/1 after the heat storage system implementation.

(Q – heat load; E – electrical load, cog. unit – cogeneration unit).



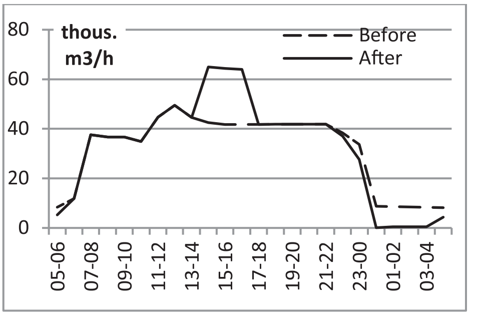


Fig. 5. Changes in electricity (MWh/h) production.

Fig. 6. Changes in natural gas (thous. m3/h) consumption.

Total savings account for ~ 1.7 million € during the year, which can be reduced to 1.3–1.4 million € in case of appearance of new heat energy sources on the right bank of Riga district heating system: biomass energy sources with total thermal capacity of 100 MW and 150 MW. Moreover, the construction of these new heat sources influences the playback time of heat storage system project. For instance, the investments of new heat energy storage are assumed to be 10.6 million €, the payback time is 10.17 years without biomass heat energy sources; 14.04 years in case of biomass heat energy sources with total heat load of 100 MW and 15.84 years under condition of biomass heat energy sources with total heat load of 150 MW.

5.2. Acceleration of Start-ups

On the one hand, the original start-ups (without improvement) are harmful from the perspective of technical and used fuel. On the other hand, the accelerated start-ups (with improvement) have a lot of benefits, which are described in detail in [10], [11]. In this subsection, the statistics and procedure of Riga CHP-2 plant starts-ups are analysed to determine the status of start-ups. The number of Riga CHP-2/1 and Riga CHP-2/2 start-ups has increased dramatically from 17 to 65 and from 22 to 99, respectively, during three years (2013–2015).

The hot start-up takes approximately 80 minutes (Fig. 7) and cold start-up is 450 minutes long (Fig. 8). It was also calculated that during the hot and cold start-ups 893.3 GJ and 5656.0 GJ of natural gas are consumed, respectively. Only hot and cold start-ups are evaluated as detrimental points. The investigation of warn run-ups is omitted in the present research.

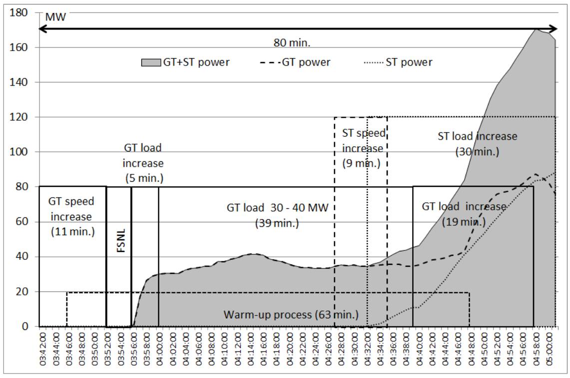


Fig. 7. Sequence and duration of hot start-up on Riga CHP-2/2 example (GT – gas turbine; ST – steam turbine; FSNL – full speed on load (gas turbine is at a full speed with little or no load)).

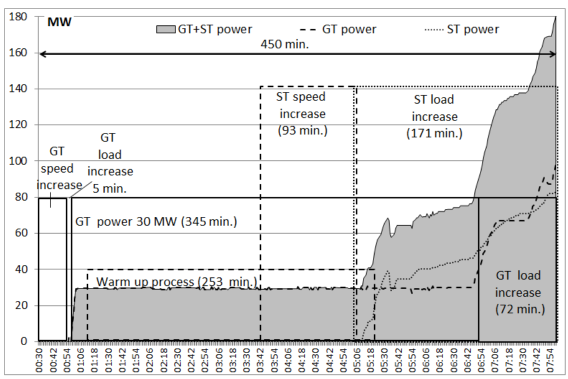


Fig. 8. Sequence and duration of cold start-up on Riga CHP-2/2 example.

The obtained results are compared with provided results in [12], which are reflected in Table 4, where start-ups are divided into four groups *"Best", "Good", "Normal", "The last"* according to the duration and consumed fuel.

Table 4

Classification and Characteristic of Start-ups

Categories	*Best*	*Good*	*Normal*	*The last*
Start-up time, minutes				
Hot start-up 0–12 h	33	41	70	97
Cold start-up >72 h	61	98	154	204
Natural gas consumption, GJ				
Hot start-up 0–12 h	508	556	756	1339
Cold start-up > 72 h	1066	1066	1070	2940

Riga CHP-2/2 plant hot start-up is close to the category *"Normal"*. The performance of cold start-up is far from the category *"The last"*. Thus, the acceleration of start-up, especially of cold start-up, can be the second step towards Riga CHP-2 plant flexibility and efficiency increase after the implementation of *OpFlex Turndown* solution. At present, three solutions are under discussion and evolution: (1) *OpFlex Variable Load* path (OpFlex VLP); (2) *OpFlex Shutdown Purge Credit*; (3) change of distributed control system logic to acceleration of the start-up of steam turbine at Riga CHP-2/2.

OpFlex VLP is gas turbine control software upgrade, which decouples gas turbine load from exhaust temperature. The upgrade provides improvements of start-ups (faster, reduction of consumed fuel, decrement of emissions, gas turbine load flexibility) and part load operation and the enhancement of maintenance and reliability [13].

OpFlex Shutdown Purge Credit provides the purge of natural gas fuel piping; isolates the fuel system with a compressed air pressurized plug; performs exhaust system and heat recovery steam generator (HRSG) purge during shut-down immediately after flameout and maintains this fully purge state by completely isolating the fuel system from the GT/HRSG flow path. The advantages and disadvantages of *VLP* and *Purge Credit* installation are provided in Table 5 [13].

Table 5

Advantages / Disadvantages and Neutral Aspects of VLP and Purge Credit

Advantages	Disadvantages	Neutral
Acceleration of start-ups is an opportunity to reduce the operation of cogeneration unit in insufficient mode – decrement of consumed fuel and produced CO_2 emissions	Expensive – approximately 1.9 million €; The risks of upgrade installation are not known completely and benefits are not completely assessed; There is not an example of *VLP* installation to 9FB machines	At present, flurry with *"the first megawatts"* is not so pronounced for CHP plants in Latvia as in other countries in Europe

There is the third option, which can be implemented instead of *VLP* and *Purge credit*. It is the acceleration of steam turbine by changing logic in distributed control system to quicken attemperator flow. This solution ensures complete use of technical resource; furthermore, the additional money investment is not necessary. It is under investigation as *VLP* and *Purge credit*.

6. CONCLUSIONS

The base load CHP plants can stay competitive after implementation of appropriate measures (solutions) with the aim to increase their efficiency and flexibility. In line with previously provided research by authors in [1], a lot of measures are proposed to improve the operation of cogeneration power plants. That is why, firstly, it is necessary to evaluate the level of CHP plant operation by assessing bottlenecks, which should be improved. Secondly, the appropriate measures should be proposed and evaluated from economical and technical point of view. Thirdly, the beneficial measures should be implemented and those unprofitable rejected. As a result of flexibility enhancement, the life time of power plants is extended.

In case of Riga CHP-2, it is necessary to reduce cogeneration unit start-up time to decrement the fuel consumption and CO_2 emission production. The installation of heat storage tank can also be beneficial, but rapid changes in energy sector in the short- and long-term impugn the implementation of this project.

REFERENCES

1. Ivanova, P., Sauhats, A., Linkevičs, O., and Balodis, M. (2016). Combined heat and power plants towards efficient and flexible operation. *2016 IEEE 16th International Conference on Environmental and Electrical Engineering (EEEIC)*, 7–10 June 2016 (pp. 230–235). Piscataway, NJ: IEEE.
2. Troy, N. (2011). *Generator cycling due to high penetrations of wind power*. Retrieved 11 May 2016, from http://erc.ucd.ie/files/theses/Niamh%20PhD%20-%20Generator%20Cycling%20due%20to%20High%20Penetrations%20of%20Wind%20Power.pdf
3. PEi. *The future role for thermal generation*. (n.d.). Retrieved 11 May 2016, from http://www.powerengineeringint.com/articles/print/volume-23/issue-5/opinion/the-future-role-for-thermal-generation.html
4. Kunickis, M., Balodis, M., Linkevics, O., and Ivanova, P. (2015). Flexibility options of riga chp-2 plant operation under conditions of open electricity market. *2015 IEEE 5th International Conference on Power Engineering, Energy and Electrical Drives (POWERENG)*, 11–13 May 2015 (pp. 548–553). Piscataway, NJ: IEEE.
5. Balodis, M., Krickis, O., and Ivanova, P. (2016). The realization of n-ergie heat storage tank project in nuremberg district heating system. *Enerģija un Pasaule*. No. 3, 40–44.
6. Zigurs, A., Kunickis, M., Linkevics, O., Stuklis, I., Ivanova, P., and Balodis, M. (2015). Evaluation of exhaust gas condensing economizer installation at riga chp plants. *REHVA Annual Conference 2015*, 6–9 May 2015 (pp. 149–154). Riga, LV: RTU Press.
7. International Energy Agency (IEA). (2014). *Energy technology perspectives 2014. Harnessing electricity's potential.* France: OECD/IEA.
8. GE Energy (2011). *OpFlex Reserve*. pp. 1–2.
9. GKM presentation (2016). *Grosskraftwerk Mannheim AG. VGB TG power plant concepts*.
10. Emberger, H., Schmid, E., and Gobrecht, E. (2005). *Fast cycling for new plants and upgrade opportunities.* Siemens AG.
11. Kehlhofer, R., Rukes, B., and Hannemann, F. (2009). *Combined-cycle gas & steam turbine power plants*. Tusla: PennWell Corp.
12. Stockmans, P.-J., and Peter, O. (2015). *Presentation about start-ups benchmarking and flexibility improvements levels.*
13. GE Power materials (2015). *Latvenergo AS budgetary proposal for OpFlex LVP and Purge Credit*.

ELEKTROENERĢIJAS TIRGUS LIBERALIZĀCIJA UN KONVENCIONĀLĀS ĢENERĀCIJAS ELASTĪGUMA LĪMEŅA UZLABOŠANA ATJAUNĪGO ENERGORESURSU BALANSĒŠANAI – VAI IESPĒJAMS PALIKT KONKURĒTSPĒJĪGAM?

O. Linkevičs, P. Ivanova, M. Balodis

K o p s a v i l k u m s

Atjaunīgo energoresursu (saules un vēja enerģija) integrācija enerģijas ražošanas procesā un elektroenerģijas cenas svārstības izmainīja konvencionālo elektrostaciju darbības režīmus, t.i., pāreja no bāzes režīmiem uz cikliskajiem darbības režīmiem. Konvencionālās elektrostacijas nav pielāgotas jauniem darbības režīmiem, tādējādi ir nepieciešams uzlabot to elastīguma līmeni, lai strādātu efektīvi no tehniskā un izmantota kurināmā viedokļa un iegūstu papildu peļņu. Ir pieejamās dažādas metodes, lai palielinātu elektrostaciju elastīguma līmeni. Pirms ievest elastīguma uzlabošanas pasākumus, jāizpēta situācija elektrostacijā un vājas vietas jāidentificē. Šajā publikācija sekojošie pasākumi apskatīti uz Rīgas TEC-2 piemēra: siltumenerģijas akumulācijas sistēmas izmantošana; koģenerācijas iekārtas darbības diapazona paplašināšana un palaišanas režīmu paātrināšana.

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APPLIED PHYSICS

DETERMINATION OF CONTACT POTENTIAL DIFFERENCE BY THE KELVIN PROBE (PART II)
2. MEASUREMENT SYSTEM BY INVOLVING THE COMPOSITE BUCKING VOLTAGE

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The present research is devoted to creation of a new low-cost miniaturised measurement system for determination of potential difference in real time and with high measurement resolution. Furthermore, using the electrode of the reference probe, Kelvin method leads to both an indirect measurement of electronic work function or contact potential of the sample and measurement of a surface potential for insulator type samples. The bucking voltage in this system is composite and comprises a periodically variable component. The necessary steps for development of signal processing and tracking are described in detail.

Keywords: *Kelvin probe, contact potential difference, surface potential.*

1. INTRODUCTION

This is a continuation (Part II) of article [1], which presents description of the corona discharge physics. Determination of the surface electric potential difference by the Kelvin probe, i.e., vibrating capacitor technique, is one of the most sensitive measuring procedures in surface physics for contact potential difference (CPD) measurement. This contactless non-destructive method is based on using the traditional Kelvin probe placed plane-parallel to the sample electrode (see Fig. 1a) at a distance d_0 in stationary state, shaping the simple two-plate capacitor *C*. Based on the previous part of the paper [1], it can be assumed that prior ohmically contacting to the back side of either the electrically conductive or the semiconductor sample electrode to the metallic probe electrode the capacitor electrodes are electrically neutral, no macroscopic electric field arises, and the solids of electrodes share the same local vacuum level.

If the external ohmic circuit is connected to the back sides of sample electrode, and probe electrode charge must flow from electrode substance with smaller work function to the electrode substance with larger work function until equilibrium of Fermi levels is achieved. This charge transfers results, in accordance with the law of Volta's serial contacts, as an electric field at the gap between two plates of Kelvin condenser and a drop of a local vacuum level across this gap. Thus, the capacitor at a stationary electrode distance d_0 capacity C is charged by charge Q, and in this case the corresponding potential difference V_{CPD} (Volta potential difference) in a gap between two electrodes is determined by difference of work functions of each electrode substance V_{CPD}=ΔΨ, see more details [1]. Thereby, CPD must be measured in an open circuit, i.e., using the dielectric such as vacuum or air between the surfaces of inner plates. One might think that V_{CPD} magnitude could be simply calculated considering relationship $Q = C\times V_{CPD}$, and taking into account that the accumulated charge Q of the capacitor and fixed capacitance C can be measured even with the fixed width of the gap between the electrodes. However, it is not so simple to pinpoint the capacitor accumulated charge.

Currently CPD determination is mainly based on Kelvin method where an external potential V_B is involved at the Kelvin probe outer circuit, which compensates the potential difference between the capacitor gap electrodes. This unique condition occurs at a potential $V_B = -V_{CPD}$ and consequently vanishes the electric field and the potential difference between Kelvin capacitor electrodes $Q \to 0$ and $V_{CPD} \to 0$. Thereby, the variable bucking potential *VB* is adjusted until the Kelvin current vanishes $i \to 0$. *VB* is equal and opposite to V_{CPD}, the electric field between the capacitor electrodes is compensated, and the zero output signal is recorded, wherein the ac current in the Kelvin probe outer circuit drops to zero.

Periodic modulation of distance between electrodes results in a periodic change of capacitance, whereby, if the potential diference V_{CPD} exists between electrodes, the ac current *i(t)* flows through capacitor external circuit. Required parameters of this modulation: frequency *f*, modulation depth and amplitude are provided by a driver mechanism. Such CPD compensation procedure is called the nulling of Kelvin probe signal *i(t)*.

At the nulling point, both capacitor electrodes become electrically neutral like in case of disconnected outer circuit. In both cases, the vibrating Kelvin probe cannot create current in an external circuit. Therefore, the basic condition when Kelvin probe does not disturb the studied process is achieved, and the measuring action practically does not influence the contact potential difference measurement.

In the traditional measuring systems, the self-nulling detection of balance point of ac current generated by capacitor is fed to the input of a preamplifier. In this case, the amplifier output voltage is mostly detected applying synchronous detection by using the lock-in amplifier (LIA) with proportional [2], [3] or integral [4], [5] feedback, referenced by probe vibration frequency. As a result, the contact potential of an automatically self-nulling system is formed at the balance point. Such a type of the feedback loop system provides good dynamic properties of V_{CPD} measurements, though it has several serious disadvantages [6]. The value of the voltage drop over Kelvin capacitor becomes negligible around $i(t) \to 0$ and close to the balance point the parasitic noise signals begin to prevail.The main disadvantage of these systems is a small signal-to-noise ratio at the balance point. Thus, at the low signal level the nulling cannot represent correct balance point, the signal-to-noise ratio becomes small and the inversion of phase can emerge. This leads to the sequel of synchronous detection. Consequently, an application of self-compensating LIA systems is limited. To overcome this limitation, the use of the off-null detection was proposed by B. Ritty et al. [7], where the balance point was determined by a linear extrapolation rather than nulling. On the basis of statistical linear correlation-regression analysis of Kelvin current as a function of applied bucking voltage V_B, the CPD can be derived generally by a good linear correlation coefficient, and errors do not exceed 10 mV. A solution to the low signal-to-noise ratio at the balance point is to use measuring methods that permit "off-null" measurements, if the mentioned errors are excluded around $i(t) \rightarrow 0$. After that the calculated data points could be processed by various fitting procedures. In modification of this method developed by I. D. Baikie [8], the peak-to-peak (ptp) output signal V_{ptp} is estimated as a function of bias voltage V_B and involves the setting of bucking potential at ± 20 mV from the balance point to permit both the high output signal and the accurate determination of in-phase noise components alongside the balance point. The balance point of a voltage drop over the Kelvin capacitor V_{CPD} and bias voltage V_B is determined by measuring the V_{ptp} value at different variable bias voltages. The Kelvin signal collected from the vibrating electrode is based on the statistical linear correlation-regression analysis of Kelvin current as the function of applied $V_{B.}$ The extrapolated value $V_{ptp} = 0$ is estimated by the data processing program. The complete control and measurement system is PC or microcontroller-steered. Voltage V_B is derived from a 12-bit digital-to-analogue converter, which is set to the range of potentials controlled step-wise around the balance point and subsequently digitised by the analogue-to-digital converter for further signal processing by the host PC. The system also incorporates the off-null detection. Application of off-null technique enables measurement of CPD to acquire the best signal-to-noise ratio and is sufficient to produce good quality work function data. The work function resolution of such a system manufactured industrially by KP Technology is of < 3meV [9].

However, the use of the off-null technique has a few disadvantages. Statistical linear correlation-regression analysis, despite its high complexity in case of area scan at many measurement points, requires the processing of the completed set of measurements [6]. Thus, the online monitoring of Volta potential difference is not possible and the result of measurement can be analysed only after experiment is finished. In addition, the application of the above-mentioned modified off-null technique is generally associated with the need of a PC with pre-installed KP extensive software and use of the external data acquisition digital control unit with a host PC data acquisition system housed in the PC system. This, of course, not only increases the measuring equipment extent and weight, but also raises production costs.

2. DETERMINATION OF CPD USING THE COMPOSITE BUCKING VOLTAGE SYSTEM

The design of our potential V_{CPD} measuring system is different in comparison with a measuring system described above; it is based on a simpler technical solution and does not require complicated software. At the same time, we have obtained high resolution in comparison with setups described above [8], i.e., 1–2 mV, besides, the proposed system provides continuous CPD measuring mode. That way the series of disadvantages mentioned above [1], [6] for such systems are eliminated, which creates preconditions of their wider dissemination and use.

An overview of our CPD measurement system arrangement in simplified form is shown in Fig. 1a. It consists of two basic units: the HEAD STAGE and DATA ACQUISITION SYSTEM (DAS). The HEAD STAGE includes Kelvin condenser C with its electrodes: the sample and the vibrating probe driven by the DRIVER mechanism [10], which is fed by a high-precision sine signal source. This arrangement generates mechanical probe electrode vibration. The PREAMPLIFIER is composed of an ultra-low bias current and low noise input operational amplifier (op-amp) with the dielectrically-isolated FET input and of a precision instrumental output op-amp [10], [11]. The input op-amp makes it possible to implement two functions. Firstly, if input op-amp inverting input is connected to Kelvin probe vibrating electrode, very low current convertion to voltage with a high conversion factor is implemented. The equivalent value of total parasitic input capacitance and corresponding problems of amplifier input are suppressed due to converter low input impedance. Hence, Kelvin probe electrode through the converter input circuit is connected to the so-called virtual ground, i.e., to the sample electrode. Secondly, the CPD compensating or bucking voltage is conveniently involved into the Kelvin capacitor external circuit through converter non-inverting input. Thanks to current-to-voltage converter low impedance, all applied bucking voltage appears in the Kelvin capacitor external circuit. Converter differential output signal is converted to the single-ended output stage using the precision instrumental op-amp.

Our potential V_{CPD} measuring system is based on the fact that at a time t it is continuously generating variable composite bucking voltage $V_B(t)$ and is pinpointing the balance point by averaging periodically synchronised data processing.

To pinpoint the potential V_{CPD}, in our case the electronically controllable variable voltage $V_B(t)$ generator is created that provides the change in the periodical symmetrical triangle wave (saw-tooth) voltage at a time t around the bucking potential balance level V_B. The polarity and the magnitude of this level determine the relevant parameters of countervailable CPD voltage V_{CPD}.

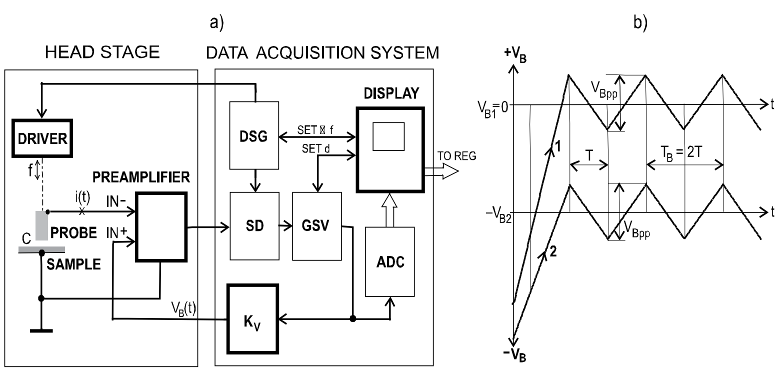

Fig. 1. Schematic diagrams of experimental contact potential difference V_{CPD} measuring system for determination of contact potential diference by Kelvin probe involving the composite bucking voltage: a) Block diagram, where *sin* generator for driver supply (DSG); synchronous detector (SD); ac voltage amplifier (K_V); stepwise variable bucking voltage generator (GSV); analog-to-digital converter (ADC). b) Variable bucking voltage $V_B(t)$ diagrams: (1) $V_{CPD} = 0 = V_{B1}(t)$, and (2) $V_{CPD} = -V_{B2}(t)$.

To illustrate this process, the changes in variable bucking signal $V_B(t)$ during the time are displayed in Fig. 1b at two balance point values $V_{B1}= 0$ and V_{B2}. Electronically controlled generator GSV (Fig. 1a) based on a digital technology plays a specific role for our data acquisition system (DAS), which generates the high precision output voltage that is stepwise linearly growing or decreasing. The bucking voltage $V_B(t)$ is formed and applied to the preamplifier non-inverting input IN+ after appropriate amplification by an amplifier $K_{V.}$ Generator GSV is controlled by the preamplifier output signal, supplied to the synchrodetector input. From SD output detected signal is supplied directly to the generator control input. At the end of each Kelvin current period *T* an appropriate polarity control signal is determined, which leads to appearance of stepwise GSV output voltage that is either linearly growing or decreasing. To synchronise the period *T*, the output signal of sine signal generator DSG employed for driver supply is used as the reference signal, which, taking into account the appropriate phase-correction, is supplied to the SD synchronising input. Generator DSG is generating the high precision sinusoidal voltage with frequency f=118.09±0.01 Hz digitally sinthesised from 48 MHz clock signal (the built-in phase locked loop (PLL) can be used to generate a high-frequency system clock), with an external quartz oscillator 16 MHz. This voltage supplied to the driver mechanism provides the Kelvin probe vibration. Every moment at the beginning of each interval *T*/256 s the preamp output signal data are digitised and almost simultaneously prerecorded and analysed in the buffer memory according to the algorithm for SD operation period $T = 1/f = 8.468$ ms. As a result of data processing, the average values of both the period and the half-period of signal are determined. Thereby the signal switching phase-sensitive half period detection allows creating the control signal of generator GSV approppriate polarities for next period *T*.

At the data acquisition system (DAS), Fig. 1a for visibility reasons displays generators DSG and GSV, synchronous detector SD and analogue-to-digital converter ADC created practically using the microcontroller ATXMEGA16A4U-A where peripheral features – dual channels DAC and ADC – are involved. In accordance with a specially drawn algorithm, one of microcontroller digital-to-analogue converter DAC channels is used to synthesise the sinusoidal voltage at the generator DSG output, but the second channel provides the stepwise voltage at the generator GSV output. The maximal voltage on GSV output should not exceed the microcontroller supply voltage *Vs*. Therefore, this voltage is practically equal to the countervailable range coverage. The voltage change step in the GSV output can be calculated as follows:

$$\Delta V_{GSV} = V_S / n \,, \tag{1}$$

where n is a number of DAC bits. In our case, if V_S = 3.3/4096 = 0.0008V, and $n = 2^{12} = 4096$, generator output voltage range is V_S=3.3V. If the range coverage is V_{RC} = 20.4 V (absolute values range from −10.2 V to +10.2V), it is required to involve a separate amplifier at the generator GSV output having voltage gain factor K_V (Fig.1a), where $K_V = V_{RC}/V_S = 20.4/3.3 = 6.2$, and $\Delta V_B = \Delta V_{GSV} \times K_V$.

Figure 1b demonstrates two examples of bucking voltage $V_B(t)$ generated as described above by appropriate values of variable contact potential difference between a conductive sample and a reference probe. From appearance of generated signal $V_B(t)$, it is possible to conclude that it consists of two stages (components). At the first, the main stage, the signal that is linearly increasing or decreasing reaches and hits the bucking voltage balance level (in example 1 it is $V_{B1} = 0 = V_{CPD}$). The voltage polarity and value can differ at different head stage starting points (not shown in figures), and, for example, can depend on previous sample measurement. If V_{CPD} value is not changing (it is constant) by the measurement time, in the both examples mentioned above the first stage is followed by the second stationary stage where the generated voltage is guided by variations of control signal at the generator GSV input, which leads to changes of voltage V_B(t) initial direction and emergence of saw-tooth oscillations around the average value of oscillation level with period $T_B = 2T$. This level characterises the level of bucking voltage at the balance moment (V_{B1} and $-V_{B2}$, respectively), which is equal and with opposite polarity to the value of respective potential V_{CPD}. The peak-to-peak amplitude of triangle voltage V_{Bpp} is chosen so that its value exceeds ± 20 mV range several times. It is due to the above-mentioned precise measurement problems of an extremely weak Kelvin current at the area of balance point compensation where the signal-to-noise ratio reaches the minimum and the noise creates an offset voltage. Taking into account (1) and the amplification factor K_V, the peak-to-peak amplitude of triangle voltage is set by the expression

$$V_{Bpp} = \Delta V_B \cdot N , \qquad (2)$$

where N is a selected number of steps. In our case, if $\Delta V_{GSV} = 0.8$ mV, $K_V = 6.2$ and $N = 32$, $V_{Bpp} = 158.7$ mV.

Accordingly, as a result of the above-mentioned and fixed [1], [6] interaction between the main linearly rising component of bucking voltage and its second – the triangular component, the variablie voltage with average value V_B (V_{B1} or types V_{B2}, see Fig. 1b) is generated. In its turn, the voltage V_B corresponds to a compensatory value of measured voltage CPD at the balance point of these both voltages and alows fixing the value CPD.

It should be noted that the chosen triangular voltage peak-to-peak amplitude V_{BPP} (2) is constant and maintains its value over the entire measuring range of contact potential diference.

The rate of speed $V_B(t)$ changes is characterised by ratio $\Delta V_B/\Delta t = V_{Bpp}/2T$, which in our case is $\Delta V_B/\Delta t$ =158.7 mV/16.9364 ms = 9.37 V/s.

The scanning of sample surface is practically carried out by many periodically repeated measurements. To shorten the total measurement time, the measurement is worked out based on shortening of the first stage of each individual measurement by increasing the speed of bucking voltage changes $\Delta V_B/\Delta t$. This is developed by an algorithm that automatically increases ΔV_B values in accordance with the Kelvin current value at the beginning of measurement. The sample surface of the CPD measuring system is provided by the two-coordinate sample positioning mechanism controlled by two stepper motors in accordance with the control program.

The mean distance d_0 between the sample electrode surface and the probe of experimental CPD measuring system is set manually proceeding from the image seen on the display. By the time of setting the installation regime for the measured sample, the plain gold layer coated over the sample standard glass plate is used, and the constant voltage is supplied to the probe gold electrode. At the output of measuring system, the voltage appears that is caused by Kelvin current, whose magnitude depends on the mean distance between electrode d_0. The voltage level for definite distance d_0 is set by more detailed manual regulation in accordance with image on the display. The distance d_0 setting procedure can be automatised [12]. The measured data (see Fig. 1a) are supplied from the analogue-to-discrete converter DAC output to the DISPLAY device, which includes the display of TFT LCD Panel SH128160T-066-L03Q. The DAC input is connected to the generator GSV output. On the display, both values are shown, which are expressed in volts with resolution 1 mV: the measured value V_{CPD} and the difference between these V_{CPD} readings and the gold probe surface potential (reference potential). Besides, there is the link "SET ± *f*" foreseen from the display device to the generator DSG for fine correction of sinusoidal frequency. The display operation is provided by the ATXMEGAI6A3U–AU type second microcontroller, which together with an optional regime switch is placed into the block of data acquisition system. At the output of display device, either the USB or the voltage-to-frequency converter with output "TO REG" can be provided for external data registration. The data acquired by the testing regime leads to a conclusion that if the output data integration time is 1s, the developed CPD measuring system for determination of the contact potential difference by Kelvin probe involving the composite bucking voltage provides the resolution of experimental measuring system in the range of ± (1–2 mV). This parameter can be improved using the 16-bit ADC instead of currently used 12-bit ADC inside the generator GSV.

The developed potential V_{CPD} measuring device is provided with gold probe, whose surface potential is comparatively stabile and makes it possible to detect V_{CPD} between the sample and the probe (as a reference). To carry out the actual work function measurements, a calibration is required because Kelvin probe needs to be calibrated in respect to the surface, whose work function is known. It is generally believed that under conditions of ambient air the gold has the work function around 4.9 eV. However, it is problematically to assess this value because the reaction of air components with the gold surface is possible. For example, if the gold films have been stored, it has been observed [13] that according to the storage time this value can reach a drift to 500 meV. The gaseous reaction studies of Kelvin probe [14] show a significant reaction of NO_2 and NH_3 with gold. There are examples [15], which show the use of gold film gaseous sensors, for example, for determination of gaseous NO_2. This provides suggestions that for precise determination of absolute work function factor the preference should be given to the measurements in the vacuum. This problem can be solved to some extent if the inert materials are used. In this case, it is necessary to carry out two CPD measurements with Kelvin probe. The measurement with the measured sample $e(\Delta\Psi_{MP})$ is taken first and afterwards with the reference material $e(\Delta\Psi_{IR})$. Subsequently, the difference of both measurement results is calculated:

$$eV_{CPD} = e(\Delta\Psi_{MP} - \Delta\Psi_{IR}) = (\Phi_{MP} - \Phi_{Au}) - (\Phi_{IR} - \Phi_{Au}) = (\Phi_{MP} - \Phi_{IR}). \quad (3)$$

Thereby, the value Φ_{Au} is excluded from the calculation and variations of gold probe output work effects by time fall away. Under ambient conditions, the use of highly oriented pyrolytic graphite (HOPG) crystal is probably one of the best methods for calibration. Its work function about 4.6 – 4.7 eV remains fairly stabile.

3. CONCLUSION

We feature a new and simple way enabling the determination of a contact potential diference (CPD) by entering the composite and time-varying bucking voltage in the Kelvin probe measuring circuit. The system is based on the generation of the electronically controllable CPD bucking voltage.

As a result of consecutive interaction of composite bucking voltage main component (raising or decreasing) and its triangular component, the variable voltage (with positive or negative polarity) is periodically generated. The averaging value of this voltage, in its turn, coresponds to a value of bucking voltage V_B compensating the voltage V_{CPD} measured in the CPD at the moment when the both voltages are balanced, wherewith it is possible to determine the value V_{CPD}. This way it is possible to avoid the row of measuring system disadvantages shown in [1], [6], which leads to the need of accurate determination of the value V_B at the moment of achieving the balance between the two above-mentioned voltages when the current in the measured circuit is close to zero. In this case, precise measurement of current is complicated because the measured signal-to-noise ratio reaches minimum, and noise brings notable errors into the measurement.

The average value of composite bucking voltage generated by our measuring system is periodically and symultaneously detected and integrated, and its value with opposite polarity matches the measured contact potential difference V_{CPD}. Thus, the system continuously carrying on the "on-line" regime automatically keeps track on the measured value and noticeably avoids measuring inaccuracy related to the determination of super-weak current in the balance area of the both mentioned signals. The need of complex computer systems used traditionally to carry on the procedures of signal extrapolation for precisely setting down the voltages within the specified measuring range is eliminated. Components of the proposed measuring system are highly integrated, and the system is compact and of small size, which decreases the operating expenses of device and broadens the possibilities of its carrying into effect.

The measuring device is designed to determine CPD in the range of +10.000V up to –10.000V on the vibrating capacitor electrode surfaces representing the sample and the Kelvin probe electrodes. In our case, the chosen triangular voltage peak-to-peak amplitude V_{BPP} is constant and maintains its value over the entire CPD measuring range.

System adjustment can be performed easily and fast. Experimental measurement system test results have shown stable measurement resolution in the range of ± (1–2 mV).

The data acquisition system of our measurement device is supplied with a display, which allows for an easy setting of the performance measuring regime and visually keeping track of the measurement procedure.

REFERENCES

1. Vilitis, O., Rutkis, M., Busenbergs, J., and Merkulovs, D. (2016). Determination of contact potential difference by the Kelvin probe (Part I). 1. Basic principles of measurements probe. *Latv. J. Phys. Techn. Sci., 2*, 48–57.
2. Palevsky, H., Swank, R.K., and Grenchik, R. (1947). Design of dynamic condenser electrometers. *Rev. Sci. Instrum*, *18*, 298–314.
3. Mitchinson, J.C., Prongle, R.D., and Farvis, W.E.J. (1971). Surface potential measurement using a rotating dynamic capacitor. *J.phys., E 4,* 525–529.
4. Petit-Cloerc, Y., and Carette, J.D. (1968). New feedback Kelvin probe. *Rev. Sci. Instrum., 38*, 933–934.
5. Blott, B.H., and Lee, T.J. (1969). A two frequency vibrating capacitor method for contact potential diference measurements. *J.* Phys., *2*, 785–788.
6. Maljusch, A. (2012). Integrated scanning Kelvin probe – Scanning electrochemical microscopy system: Design, development and applications. *Diss*. 1–245.
7. Ritty, B., Wahtel, Ott, F., Manquenouille, R., and Donnet, J.B. (1980). New application of the Kelvin method involving the scanning of the bucking voltage. *Rev. Sci. Instrum., 51* (10), 1421–1423.
8. Baikie, I.D., van der Werf, K.O., Broeze, J., and van Silfhout, A. (1989). Automatic Kelvin probe compatible with ultrahigh vacuum. *Rec. Sci. Instrum. 60,* 930.
9. KP Technology. USA Inc. Available at *www. kelvinprobe.com*
10. Vilitis, O., Fonavs, E., and Muzikante, I. (2001). A system for measuring surface potential by the Kelvin-Zisman vibrating capacitor probe. *Latv. J. Phys. Techn. Sci.*, *5*, 38–56.
11. Rossi, F. (1992). Contact potential measurement: The preamplifier. *Rev Sci. Instr., 63* (7), 3744–3751.
12. Neufeld, A.K., Bond, A.M., and Cole, I.S. (2003). Construction and operation of a Kelvin probe instrument. Chapter 3, 29–88.
13. Hansen, W.N., and Johnson, K.B. (1994). Work function measurements in gas ambient. *Surface Science*, *316,* 373–382.
14. Toda, K., Ochi, K., and Sanemasa, I. (1996). Non-sensing properties of Au thin film. *Sensors and Actuators, B 32,* 15–18.
15. Ostrick, B. (2000). Die Untersuchung der Karbonat – Kohlendioxid – Wechselwirkung im Feuchtefilm der Oberfläche. Diss. 1 – 131.

KONTAKTPOTENCIĀLU STARPĪBAS NOTEIKŠANA AR KELVINA ZONDI (II DAĻA) 2. MĒRĪŠANAS SISTĒMA, IESAISTOT KOMPOZĪTU PRETSPRIEGUMU

O. Vilītis, M. Rutkis, J. Busenbergs, D. Merkulovs

K o p s a v i l k u m s

Rakstā esam parādījuši iespējas izveidot augstas precizitātes, kompaktu, lētai un ērtai lietošanai kontakta potenciālu starpības mērīšanas veidu ar Kelvina zondi, kas ļauj regulāri noteikt kontakta potenciālu starpības (CPD) spriegumu V_{CPD}, ievadot šīs zondes mērīšanas ķēdē kompozītu un laikā periodiski mainīgu kompensējošu pretspriegumu. Kompozītā pretsprieguma galvenās - augoša vai krītoša sprieguma komponentes un otras – trīsstūrveida sprieguma komponentes secīgas mijiedarbības rezultātā, tiek periodiski ģenerēts pozitīvas vai negatīvas polaritātes mainīgs spriegums. Šī sprieguma vidējotā vērtība savukārt atbilst pretsprieguma V_B lielumam, kas kompensē mērāmā CPD spriegumu V_{CPD} abu šo spriegumu balansa brīdī un, līdz ar to, ļauj noteikt V_{CPD} vērtību. Ar to tiek sniegta iespēja izvairīties no virknes mērīšanas sistēmu trūkumiem, norādītiem [1], [6], ko izraisa nepieciešamība precīzi fiksēt V_B vērtību tieši minēto spriegumu balansa brīdī, kad strāva mērīšanas ķēdē pietuvināta nullei un tās precīzu mērīšanu sarežģī mērāmā strāvas signāla un trokšņa attiecības, kas mērāmās strāvas apgabalā sasniedz minimumu un trokšņi ienes ievērojamas kļūdas mērījumā.

Mūsu mērīšanas sistēmā ģenerētā kompozītā pretsprieguma vidējā vērtība tiek periodiski digitālā veidā sinhroni detektēta un integrēta, un tās pretējās polaritātes lielums atbilst mērāmajam CPD spriegumam V_{CPD}. Līdz ar to sistēma nepārtraukti '*on-line*' režīmā automātiski seko mērāmajam lielumam un ievērojamā mērā apiet mērīšanas neprecizitātes, saistītas ar ļoti vājas strāvas noteikšanu abu minēto signālu balansa apgabalā. Tādējādi atkrīt sarežģītu datorsistēmu nepieciešamība, kas tradicionāli tiek pielietotas, lai veiktu signālu ekstrapolēšanas procedūras, precīzi nosakot sprieguma vērtības norādītajā mērīšanas apgabalā. Piedāvātās mērīšanas sistēmas komponentes ir augsti integrētas, un tā ir izveidota kompakta un izmēros maza, kas, kopā ņemot, samazina mērierīces ražošanas izmaksas un paplašina tās pielietošanas iespējas.

Izveidotās eksperimentālās sistēmas pārbaudes rezultāti CPD mērīšanas robežās no +10.000V līdz – 10.000V ir pierādījuši stabilu ± (1–2 mV) mērīšanas izšķirtspēju. Mūsu gadījumā izvēlētā kompozītā pretsprieguma trīsstūrveida sprieguma komponentes pilna maksimumu amplitūda V_{Bpp} ir pastāvīga un saglabā savu vērtību visā CPD sprieguma V_{CPD} mērīšanas diapazonā.

Mērīšanas sistēma ir apgādāta ar displeju, kas ļauj ērti uzstādīt mērījumu izpildes režīmu un vizuāli sekot mērīšanas gaitai.

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