Silesian J. Pure Appl. Math.
vol. 7, is. 1 (2017), 5–20

Olha SHULYMA[1], Vira SHENDRYK[1], Algirdas PAKSTAS[2]

[1]Sumy State University, Sumy, Ukraine

[2]Institute of Mathematics and Informatics, Vilnius, Lithuania

THE MODEL OF DECISION-MAKING IN SELECTING THE OPTIMAL CONFIGURATION OF THE HYBRID RENEWABLE ENERGY SYSTEMS

Abstract. The purpose of this study is twofold: first, it is aimed at determining the architecture, energy balance of the system and the operational logic of the requests for energy use. Second, a defining a methodology that can help energy planners in the choice of the more appropriate alternatives of hybrid renewable energy system. Based on energy balance and operational logic within HRESs is proposed to conduct optimization research within socio-economic and energy efficiency scenarios. This research is proposed to use within DSS that can support the decision makers in selecting criteria, alternatives and trade-offs, thus making the energy planning simple. The methodology is divided in 3 steps: The selection of system structure in general, the determination of parameters of the system elements in all possible variants, and finally the estimation of efficiency and choosing the optimal variant of the system. For each alternatives is calculated the utility function within scenarios.

2010 Mathematics Subject Classification: 98U35, 90-08.
Keywords: renewable energy sources, hybrid renewable energy system, energy balance, operational logic, optimization model, decision support system, energy efficiency.
Corresponding author: O. Shulyma (o.shulyma@ssu.edu.ua).
Received: 23.01.2017.

1. Introduction

Present rate of all the energy consumption is growing very fast. Nowadays there is a huge interest to development of the renewable energy sources (RES) in the energy supply chain. Various forms of RESs using solar and wind energy are proposed. Solar energy has a huge potential of 1.8×10^{11} MW [9], which is many times larger than total energy consumption of the world. Assessing of the wind energy potential is much more difficult and depends on the location. For example average wind speed in different countries onshore may vary from 1.8 to 4.3 m/s [6]. Current stage of development of the RESs in Ukraine was considered in [10]. The focus of our research is on defining general architecture and its operation rules for Hybrid RESs (HRES) having both renewable energy sources as well as access to the External Power Grid (EPG). Such HRESs will be used in small localities which are very sensitive to the costs of the energy. In such approach significant number of consumers will produce energy for their own needs as well as may send surplus to the external grid. Such implementation decreases energy losses during transportation as generators are situated next to consumers. Planning, design, installation and operation of HRESs are all complex tasks and shall be performed phase by phase and considered in total context from Request to Energy:

Planning(Request,Requirements,TP) =>
Design(Requirements,Drawings,TD) =>
Installation(Drawings,System,TI) =>
Operation(System,Energy,TO)

Here Request (formal or informal) is input to the Planning phase and has to be translated to the Requirements during Planning Time TP. Design phase is accepting Requirements and has to produce Drawings (a set of installation technical documentation) during Design Time TD. Similarly, Installation phase is producing working System during Implementation Time TI. Operating System is producing Energy during Operation Time TO.

The methodological basis of the planning process of HRES is system analysis, based on the process of building a generalized system model. In practice, this is due to the creation of relevant information decision support systems that provide advices on choosing HRES components.

Scientific and methodological bases of modeling energy systems discussed in the works such scientists as Lazarou, D.S. Oikonomou, L. Ekonomou, T.V. Ramachandra, I.M. Muslih, Y. Abdellatif. Issues of energy efficiency are considered by LI. Kytskay. The technology of management of autonomous power systems with RES is considered in the works of H. Dagdougui, R. Minciardi, A. Ouammi, M. Robba, R. Sacile. The issue of information decision support in the design of grid with RES are considered in the works of C. Tiba, ALB Candeias, N. Fraidenraich, Choong-Sung Yi, Jin-Hee Lee, Myung-Pil Shim, DL. Bessette, J. Arvai, V. Campbell-Arvai, W. Gowharji. Despite the widespread use of information technology to solve specific problems, today no single comprehensive approach to solve the problem of improving the quality of decision-making processes in the planning the structure of hybrid energy system with renewable energy. The architecture of such DSS is presented in [11].

The rest of the paper is organized as follows. Section 2 is presenting architecture and energy balance of the HRES in a small neighbourhood. Section 3 is devoted to characterization of the energy usage and generation in a small neighbourhood. Operational logic of the requests for energy use or supply is considered in Section 4. Section 5 is considering the formulation of the making decisions problem. Sections 6 and 7 is devoted to describing models of selection the HRES structure. Conclusions are presented in the Section 8.

2. Architecture and energy balance of the HRES in a small neighborhood

It is assumed that the legal entity operating HRES (HRES Community) is defining its operational goals, policies, etc. HRES Community is responsible for the costs incurred as a result of designing, installing and operating of the HRES as well as for obtaining, exploiting and sharing benefits/profits to its members.

Figure 1 depicts typical architecture of the HRES in a small neighborhood comprising of the few households with possible commercial/industrial activities (farms, workshops, etc). Here energy is generated using sources such as Photovoltaics (PV) elements (Solar Panels) installed on the roofs of the houses or nearby land (denoted as Es energy) and Wind Turbines installed where it is suitable (denoted as Ew energy). Energy is stored in the Power Storage Bank (PSB) for the future use (denoted as Eb energy when used or Ebc when charged). Additionally, HRES is connected to the External Power Grid (EPG) which can be serving as both a source of the additional purchased energy (denoted as Egp energy) and a sink to where surplus energy could be supplied and potentially sold for a certain price (denoted as Egs energy). EPG is assumed as existing power network belonging to the EPG Operator. It requires installing of the Power Gateway Station (PGS) which provides routing of the energy in and out of the HRES as required.

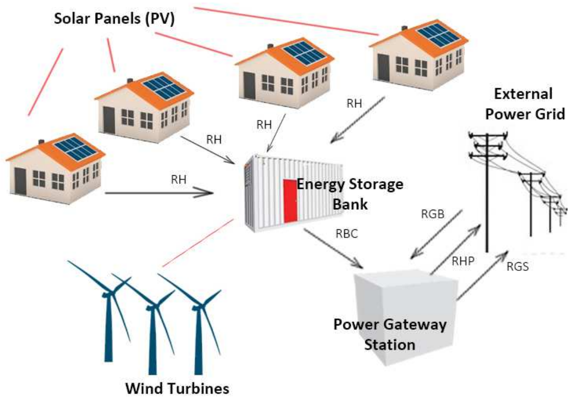

Fig. 1. Architecture of HRES in a small neighborhood

Total energy balance in the HRES is shown in Figure 2. Here are defined energy requests as well as sources and parameters influencing need to purchase or opportunity to sell energy.

RH := SUM(1..N, Rhi)	-- Current ∑ of Rhi requests from N households
0 ≤ Es ≤ Esmax	-- Current solar energy Es is between 0 and Esmax
0 ≤ Ew ≤ Ewmax	-- Current wind energy Ew is between 0 and Ewmax
0 ≤ Ebmin ≤ Eb ≤ Ebmax	-- Current PSB capacity Eb is between Ebmin and Ebmax
Ea1 := Es + Ew	-- Current available solar and wind energy
Ea2 := Ea1 + Eb	-- Current available solar, wind and battery energy
Erp := RH – Ea	-- Current deficit of energy
Esale-max := Ea2 - RH	-- Current maximum energy for sale to EPG
0 ≤ Esale ≤ Esalemax ≤ Eo	-- Energy for sale to EPG is between 0 and Esalemax and is -- limited by maximum out line capacity Eo

Fig. 2. Total energy balance in the HRES

3. Characterization of the energy usage and generation in a small neighborhood

Although the sun and wind are an inexhaustible source of energy, but their disadvantage is the stochastic nature of the flow of energy, depending on the season, time of day and weather conditions. From the other side, the energy needs of consumers also have a random character that is not dependent on the electricity generation. Thus, defining energy consumption and generation patterns in the HRES is essential for producing Requirements for the Design as well as for setting modeling and simulation parameters in the Decision Support System.

3.1. Energy usage characteristics

As an example and for further verification and implementation, it was decided to make first studies for Sumy area, Ukraine, as a place where research is conducted. In future this model is going to be general and can be used for any region.

Figure 3 shows example of the energy usage for December 22, 2015 which was selected as the shortest day of the year during which it was required the highest amount of electricity for lighting of the house as well as it is the shortest light day which directly affects output of the solar panels. Thus, this date is representing the worst operating conditions for PV sources and simultaneously the heaviest energy demand.

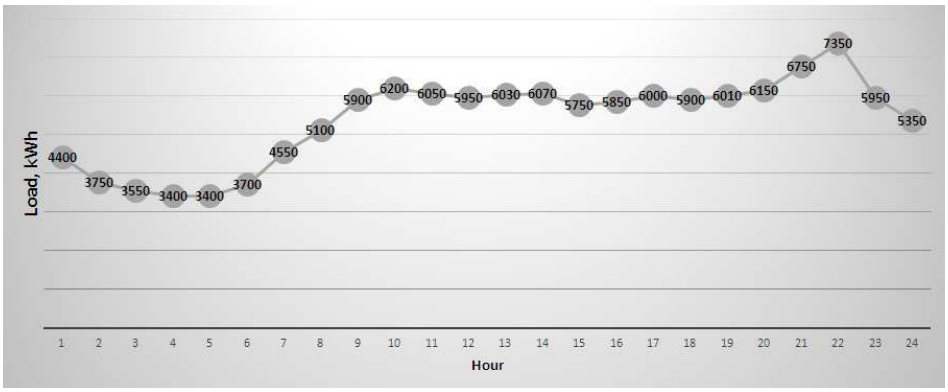

Fig. 3. Energy consumption during 22 December, 2015 in the private household in Sumy area

These data are obtained from the local energy company Sumyoblenergo [12] and are representative for a typical private house in Sumy area, Ukraine. From this graph it is clear that used energy was fluctuating between minimum 3400 (at 04:00 and 05:00) and maximum 7350 (at 22:00) Watts and the average request from household was 5380 Watt.

Power of electrical load required by the consumers is represented by the probability-statistical model which defines the daily schedule of the design load of the object for each day of the year Ppi as follows

$$Ppi = \bar{P}i \times Pmax \times (1 \pm \beta \times \sigma(Pi) \times Kc,$$

where $\bar{P}i$ – the expectation of the load at the time i, $Pmax$ – maximum load, β – the reliability coefficient, σ – mean square deviation, and Kc – seasonality factor.

3.2. Energy generation characteristics

Suitability of the solar and wind energy sources very much depends on the geographical location and climate conditions. Energy generation depends on the following factors:

- Amount of the solar radiation in the given time of the day in the given day of the year in the given point on the Earth surface depending on sun position on the sky – defines daily cyclicity of the sun radiation and as a result cyclicity and volume of a power generated by the PV components;
- Weather and season conditions affecting amount of solar radiation and strength/direction of the wind – defines variability of generated energy;
- Total number and power of the individual generation components (PV panels/wind turbines) – defines maximal possible outputs in each time t;
- Periodical (planned) maintenance of the components (cleaning, tuning, servicing, replacing, etc) – defines periodical (planned) reduction of the generated power;
- Occasional outages of the components requiring repairs or replacements – defines unplanned reduction of the generated power.

4. Operational logic of the requests for energy use or supply

According to the suggested HRES architecture requests for energy use or supply within HRES or between HRES and EPG could be as follows:

- RH: requests from individual households to HRES for satisfying domestic/industrial use (i.e. total sum of the Rhi);
- RBC: from PSB to HRES/PGS/EPG for recharging;
- RHP: from HRES via PGS to EPG for purchasing Egp energy for satisfying domestic/industrial use (i.e. in a case of low Es+Ew/Es+Ew+Eb power);
- RGS: from the HRES via PGS to EPG for selling of the surplus energy;
- RGB: from the EPG via PGS to HRES for buying of the surplus energy.

We assume that power requests are coming as random sequences of events. Each type of request RHi/RHPi/RBCi/RGBi/RGSi in general is characterized by its discrete Time Ti, finite Time Length TLi, finite Energy Ei associated with the request (power volume), Priority Pi and Cost Ci.

RHi/RBCi/RHPi/RGSi/RGBi = (Ti, TLi, Ei, Pi, Ci)

Operational logic of HRES is presented in Figure 4. Here for simplicity are omitted instant discrete values of times, requested powers, priorities as well as costs and only generalized value of RH is used. Also, conditions such as "UNTIL Tx=0" shall be understood as repeated generation of the request during specified period of time. Obviously, end users are not expected to generate their Rhi with attached time limit TL. It is rather a task for HRES control system to set suitable values for the TL intervals during which energy could be purchased from EPG. This means that in the situation when there is not enough Ea to satisfy total RH there could be generated repeated RPHi until either Ea or RH are changed and the need for purchasing is expired.

It is important to introduce the logic for purchasing and selling of the energy from/to EPG into the overall operating scheme of the HRES right from the design phase because adding it later to the live system could be problematic. As a temporary measure some fixed default prices can be allocated per energy unit (e.g. KWh) which can be later on assigned to the realistic floating market values.

Effectiveness of the system is usually evaluated by looking at its performance and cost. In the case of HRES it is suitable to use non-interrupted power supply to the customers, Deficiency of Power Supply Probability (DPSP) and Related Excess Power Generated (REPG) [7]as well as Cost Of Energy (COE) of a separate unit [1, 4, 8].

```
REPEAT
GET(RH)                                      -- Get total energy request
IF (Eb ≤ Ebmin) OR                           -- If battery low OR
          ((Ebmin < Eb < Ebmax)                        -- battery good
                    AND (RH=0))                                  -- AND no other requests
          THEN (RBC(Ec,HRES);                          -- then generate charging request
          RH := RH + Ec)                               -- and adjust total request RH
Ea := Ea1 – SOLD(EPG)                        -- Available power minus already sold
IF RH ≤ Ea THEN USE(Ea,RH)                   -- If enough then use Ea to satisfy RH
IF RH > Ea THEN Ea := Ea + Eb                -- If not enough then add battery
IF RH ≤ Ea THEN USE(Ea,RH)                   -- If enough then use Ea to satisfy RH
IF RH > Ea THEN RHP(RH-Ea,Tp,EPG)            -- If not enough then request RH-Ea
IF RHP(OK) THEN BUY(RH-Ea) UNTIL Tp=0        -- If OK then buy extra RH-Ea during Tp
IF Ea > RH THEN RGS(Ea–RH,Ts,EPG)            -- If ∃ surplus then offer it to sell during Ts
IF RGS(OK) OR RGB                            -- If sell accepted or ∃ request for surplus
          THEN SELL(Ea–RH) UNTIL Ts=0                  -- then sell surplus to EPG during Ts
IF CHARGING(FINISH) THEN RH:= RH–Ec          -- If charged then adjust total RH
UNTIL STOP
```

Fig. 4. Pseudocode for operational logic of the HRES

5. The formulation of the making decisions problem

According to the suggested HRES common architecture the basic task of selecting the HRES structure is considered in the next statement. It is given:

- The set of RES items (of the system $E = (i), i = \overline{1, n}$).
- The typical variant of HRES structure $s \in S'$, where E – the set of possible variants of HRES structures, which are differ by the characteristics of RES.
- Costs on system creation ci, $i = \overline{1, n}$.

It is necessary to determine the best variant from a variety of HRES structures $s^0 \in S$, where S – is available set of options with the defined limits on the cost and performance efficiency.

The decision to optimize is proposed to do according to the following scenarios: socio-economic in terms of energy cost (COE) and energy-efficient scenario in terms of REPG – related excess of power generated.

6. The model of selection the HRES structure

Generally the set of tasks of making decision about HRES structures can be presented as following:

$$Option = \left\{Step_i, i = \overline{1,3}\right\}$$

Step1 – The selection of system structure. The task is to determine the variant of the HRES $s^0_{ER} \in S^*$ by clarifying the set of system elements E, evaluation of properties of the variant in the criterion space $K(s^0_{ER})$ with the limitations on the level of effect Q^* and cost C^*.

$$Step^1 : \left\{Objs, s, S^*, B, B, Q^*, C^*\right\} \rightarrow \left\{E^*0, s^0_{SR}, K(s^0_{SR})\right\}$$

where B is the set of the HRES items parameters.

Step2 – the determination of parameters of the system elements. Solution provides making such changes to the HRES structure, that a set of parameters B and items E lead to the most efficient system operation.

$$Step^2 : \left\{Objs, s, S^*, B, B, Q^*, C^*\right\} \rightarrow \left\{B^*0, s^0_B, K(s^0_B)\right\}$$

where B^0 is the optimal variant of parameters of system elements, s^0_B – the variant of the system with the optimal values of the parameters, $K(s^0_B)$ – the evaluation of the received variant s^0_B by the Criteria.

Step3 – the estimation of efficiency and choosing the optimal variant of the system. During this step is conducting assessment of variants oh HRES structure $s \in S^*$ in the criterion space (s) and choosing the optimal variant $s_0 = argoptK(s), s \in S^0$.

The solving of this task is based on structured (E) and technical (B) characteristics of the system, with the limitations on the level of effect Q^* and cost C^*.

$$Step^3 : \left\{Objs, s, S^*, B, B, Q^*, C^*\right\} \rightarrow \left\{S^0, K(S^0)\right\}$$

The proposed step-by-step process of choosing optimal HRES configuration allows to structure the process of forming optimal system variant and get more precise evaluation of final system.

6.1. The approach of multicriterial estimation of efficiency

The task of making a decision – is the task of selecting one variant from the set of S by the person who makes the decision (PD), which leads to the best advantage of results in terms of PD $s^0 \in S$. To solve this task its necessary to determine the ratio of advantages of alternative variant of the structure on the set of all possible S, and then choose the best configuration.

The advantage R of system configuration $s \in S$ its proposed to determine through its utility: where $P(s)$ – the function of the utility of alternative configuration $s \in S$ $(0 \leqslant P(s) \leqslant 1)$. This approach This approach is associated with the need to determine the objective function $P(s)$, and its optimization will lead to the selection the most effective variant of system configuration.

In general, among models of multicriterial selection are used function of general utility, which are built based on additive scheme of compromise.

$$P(s) = \sum_{i=1}^{m} \lambda_i \varepsilon_i(s),$$

where $P(s)$ – the function of the utility of alternative configuration s, m – the number of partial Criteria, λ_i – the coefficient which characterized the degree of importance of the criteria $k_i(s), \sum_i = \lambda_i(s) = 1, \lambda_i(s) \geqslant 0, i = \overline{1,m}$, $\varepsilon_i(s)$ – the function of the utility of partial criteria $k_i(s)$.

If the vector of benefits is defined $\lambda = \lambda_i, i = \overline{1,m}$ and it is known the type of all utility function $\varepsilon_i(s), i = \overline{1,m}$, then the task of choice for additive scheme can be reduced to the next optimization problem:

$$s^0 = argmax P(s), \qquad s \in S.$$

Traditionally the determination of weighting coefficients vector is performed by experts, that use methods of ranking, marks assigning, consistent advantages or paired comparisons. Recently for selecting values of weighting coefficients vectors (advantages) in the multivariate assessment tasks is increasingly used fuzzy logic.

The utility function should meet certain requirements [5] be monotonic and dimensionless; have a single interval of changes (eg, from 0 to 1); be invariant to the type of extremum of partial criterion (min or max); allow to realize both linear and nonlinear dependence from the the parameters of the system. These requirements meet the next form of utility function [3]:

$$\varepsilon_i(s) = \left(\frac{k_i(s) - k_i^-}{k_i^+ - k_i^-}\right)^{\mu_i},$$

where $k_i(s)$ – the value of criteria for system configuration; k_i^+, k_i^- – max and min value of criteria respectively; μ_i – the parameter that determines the type of dependence. If $\mu_i = 1$ then is realized a linear relationship, if $0 < \mu_i < 1$ – convex, if $\mu_i > 1$ – concave.

6.2. The optimization model of selection the HRES structure in terms of the socio-economic scenario

The socio-economic scenario is calculated based on value of cost of energy (COE). COE is an economic evaluation tool for the energy production in integrated system which includes all recurring and non-recurring costs over project lifetime. It is defined as the ratio of the total annualized cost of system (TAC) to the annual electricity production (TALE) by the system.

$$COE = \frac{TAC}{TALE}.$$

In opposite to TALE (historical data), the annualized cost of system is the sum of the annualized capital cost ($C_c ap$), the annualized replacement cost ($C_r epl$), and the annualized maintenance cost ($C_m aint$) of all components of system.

$TAC = C_c ap + C_r epl + C_m aint$

Maintenance and replacement cost occur during the project life while capital cost occurs at the beginning of a project. In view of the proposed formalization, the mathematical model of the selecting the HRES structure in terms of the socio-economic scenario can be presented as:

$$\begin{cases} COE(s) \to min, s \in S) \\ REPG(s) \geqslant REPG(s)^* \\ DPSP(s) \leqslant DPSP(s)^* \end{cases}$$

where $COE(s)$ – the objective function of installation costs; $DPSP(s)$ – the limit values of the Deficiency of Power Supply Probability (DPSP); $REPG(s)$ – the limit values of the energy efficiency coefficient of system.

Taking off constraints in the model, we obtain a mathematical model of socio-economic scenario without restrictions.

6.3. The optimization model of selection the HRES structure in terms of the energy efficiency scenario

As a result of the unstable external influence of the environment on the system, the level of energy production can be insufficient to satisfy consumption. Desirable goal is to build the HRES with a such configuration that can cover the maximum consumption in the household. In view of this the energy efficiency of system is understood as its ability to generate maximum amount of electricity despite the negative influence of environmental factors, e.g. adverse weather conditions.

The assessment of energy efficiency is proposed to conduct in terms of REPG – The Relative Excess Power Generated. According to the operational logic, if energy generated by HRES exceeds required amount $RH(t)$, then the excess energy is accumulated in the PSB until reaching its maximum value E_{Bmax}. After that these excesses can be sold or, if not sold, wasted. If the amount of generated from RES energy exceeds the energy required to the consumer at a particular time, the excess energy will accumulate in the battery until the value of the battery power reaches the maximum value E_{Bmax}. Continuation of this situation leads to the presence of excessive power generation EPG, hourly value which is calculated by the formula:

$$EPG(t) = E_{gen}(t) - \Big(E_L(t) + \frac{E_{Bmax}(t) - E_B(t-1)}{\eta_B}\Big),$$

where $E_{gen}(t)$ – hourly value of generated electricity from RES; $E_L(t)$ – consumer electricity needed at time t; η_B – the battery charging efficiency; $E_B(t)$ – the amount of $E_B(t)$ at time t, where battery is discharge, time t shows real time, where electricity should be generate.

The value of REPG for the period T, which equals one year, calculated by the formula:

$$REPG(t) = \frac{\sum_{t=1}^{T} EPG(t)}{\sum_{t=1}^{T} E_L(t)},$$

where the generated energy will be insufficient for the needs of the consumer and the amount of energy in the battery reaches a minimum E_{Bmin}, hourly energy deficit DPS value calculated by the formula:

$$EPG(t) = E_L(t) - E_{gen}(t) - E_B(t-1) + E_{Bmin}(t).$$

Meaning the DPSP criteria for a year of the system:

$$DPSP(t) = \frac{\sum_{t=1}^{T} DPS(t)}{\sum_{t=1}^{T} E_L(t)}.$$

In view of the proposed formalization, the mathematical model of the selecting the HRES structure in terms of the energy efficiency scenario can be presented as:

$$\begin{cases} REPG(s) \to max, s \in S) \\ COE(s) \leqslant COE(s)^* \\ DPSP(s) \leqslant DPSP(s)^* \end{cases}$$

where $REPG(s)$ – the objective function of energy efficiency; $DPSP^{*}$ – the limit values of the Deficiency of Power Supply Probability; COE^{*} – the limit values of the system cost.

Taking off constraints in the model, we obtain a mathematical model of an energy efficiency scenario without restrictions.

6.4. The total optimization model of selecting the optimal HRES structure

To be able to select the most suitable variants in solving problems of selecting the structure of system its proposed multicriteria mathematical model that uses proposed scenarios and combines the capabilities of mathematical models of partial single criterion in scenarios.

$$\begin{cases} COE(s) \to min, s \in S) \\ COE(s) \leqslant COE(s)^{*} \\ REPG(s) \to max, s \in S) \\ REPG(s) \geqslant REPG(s)^{*} \end{cases}$$

To select a unified solution is proposed to use the theory of utility, according to which expert estimates alternative within scenarios by partial sets of criteria and gives them some utility $P(s)$ and selects the best alternative according to its value within scenario. After selecting the best alternatives (plurality $S^{''}$) within scenarios is conducted pairwise comparison of the best alternatives from different scenarios in a new (final) scenario, where the criteria $DPSP(s)$ is optimized. The optimization task of selecting the final alternative HRES configuration can be presented as:

$$\begin{cases} DPSP(s) \to min, s \in S^{''} \\ DPSP(s) \leqslant DPSP(s)^{*} \end{cases}$$

7. Case study: selecting HRES structure using the proposed procedure

To show the efficiency of the proposed method, experimental verifications had carried out. In this example, as the object of observation are the predefined configuration of HRES. The test research of model was based on the 5 configurations which are shown in Table 1.

Table 1

HRES alternatives

n	PV panels	Wind Turbine	Battery
1	ACS-50D	Techmlv1kw	Varta lad60
2	ACS-100D	Techmlv1kw	Varta lad260
3	ACS-250D	Techmlv3kw	Varta lad260
4	ACS-100D	Techmlv5kw	Varta lad115
5	ACS-250D	Techmlv5kw	Varta lad2600

These configurations differ by own characters of PV panels, Wind Turbines and batteries. These characters include: PV panels is characterized by its own power, the number of PV modules, installation cost. Wind turbines are defined by power, blades area, installation cost. Battery is characterized by capacity and price. All of these installations are presented on market, thus it may be difficult to layman choose one configurations instead others. The calculation is performed for different alternatives. Results have shown (Fig. 5).

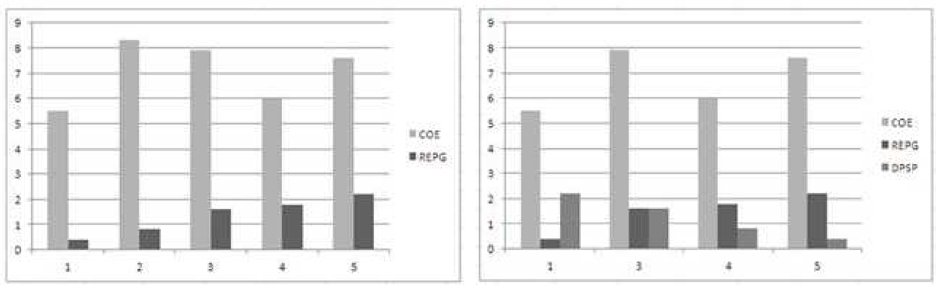

Fig. 5. Results of calculation

At the first stage is calculated COE and the REPG within their scenarios. For further study from socio-economic scenario were chosen alternatives number 1, 4, 5 and from energy efficiency scenario were chosen alternatives number 3, 4, 5 as those which have the best scores within scenarios. These alternatives form Pareto-optimal set of alternatives, which are compared within last scenario in terms of DPSP. Alternative number 5 is the optimal configuration, where COE and DPSP have gone to minimum and REPG has reached the maximum.

8. Conclusions and future work

A problem of defining and assessing of the energy balance and operational logic within HRESs harnessing solar and wind power for the use within small neighborhood have been considered in this paper. Characterization of the energy usage and generation in a small neighborhood is performed with the focus on assessment of the solar and wind energy potential.

During this study has been created a model of decision-making support regarding to the electrification of households with hybrid renewable energy system. Obtained solution allows to select the best HRES configuration within two independent scenarios: socio-economic and energy efficiency. Based on the proposed formalization of partial criteria it was firstly combined into a united mathematical model the task of selection the HRES structure in terms of COE, REPG, DPSP, where making decision goes through all by connected steps.

The proposed mathematical model of selecting the HRES structure is expanding the methodological basis of the HRES design process.

Future work will focus on introduction a decision making support method, based on fuzzy logic for ranking alternative actions within scenarios, as well as development of the appropriate case tools to facilitate the analysis and the determination of fuzzy algorithms adapted to complex hybrid systems.

References

1. Ai B., Yang H., Shen H., Liao X.: *Computer-aided design of PV/wind hybrid system.* Renewable Energy **28**, no. 10 (2003), 1491–1512.
2. Angelis-Dimakis A., Biberacher M., Dominguez J., Fiorese G., Gadocha S., Gnansounou E., Robba M.: *Methods and tools to evaluate the availability of renewable energy sources.* Renew. Sustain. Energy Rev. **15**, no. 2 (2011), 1182–1200.
3. Beccali M., Cellura M., Mistretta M.: *Decision-making in energy planning. Application of the Electre method at regional level for the diffusion of renewable energy technology.* Renewable Energy **28**, no. 13 (2003), 2063–2087.
4. Belfkira R., Zhang L., Barakat G.: *Optimal sizing study of hybrid wind/PV/diesel power generation unit.* Sol. Energy **85**, no. 1 (2011), 100–110.

5. Bilal B.O., Sambou V., Kébé C.M.F., Ndiaye P.A., Ndongo M: *Methodology to size an optimal stand-alone PV/wind/diesel/battery system minimizing the levelized cost of energy and the CO2 emission.* Energy Procedia **14** (2012), 1636–1647.
6. Hoogwijk M., Graus W.: *Global potential of renewable energy sources: a literature assessments.* Background Report PECSNL072975. By order of REN21 – Renewable Energy Policy Network for the 21st Century.
7. Kaabeche A., Belhamel M., Ibtiouen R.: *Techno-economic valuation and optimization of integrated photovoltaic/wind energy conversion systems.* Sol. Energy **85**, no. 10 (2011), 2407–2420.
8. Koutroulis E., Kolokotsa D., Potirakis A., Kalaitzakis K.: *Methodology for optimal sizing of stand-alone photovoltaic/wind-generator systems using genetic algorithms.* Sol. Energy **80**, no. 9 (2006), 1072–1088.
9. Parida B., Iniyan S., Goic R.: *A review of solar photovoltaic technologies.* Renew. Sustain. Energy Rev. **15**, no. 3 (2011), 1625–1636.
10. Shendryk V., Shulyma O., Parfenenko Y.: *The Topicality and the peculiarities of the renewable energy sources inte-gration into the Ukrainian power grids and the heating system.* Promoting Sustainable Practices through Energy Engineering and Asset Management, V. González-Prida, A. Raman (eds.). Engineering Science Reference, Hershey 2015, 162–192.
11. Shulyma O., Davidsson P., Shendryk V., Marchenko A.: *The architecture of an information system for the management of hybrid energy grid.* Ann. Comput. Sci. Inform. Syst. **6** (2015), 281–288.
12. Sumyoblenergo, https://www.soe.com.ua/.