Strojniški vestnik - Journal of Mechanical Engineering 60(2014)4, 274-282
© 2014 Journal of Mechanical Engineering. All rights reserved.
DOI:10.5545/sv-jme.2013.1199
Original Scientific Paper
Received for review: 2013-05-10
Received revised form: 2014-01-15
Accepted for publication: 2014-01-29

Improved Integration of Renewable Energy Sources with the Participation of Active Customers

Marko Corn[1,2]* – Gregor Černe[1] – Igor Papič[2] – Maja Atanasijević-Kunc[2]
[1] INEA, Slovenia
[2] University of Ljubljana, Faculty of Electrical Engineering, Slovenia

European countries are promoting the use of renewable energy sources in order to reduce their dependence on imported energy. Renewable sources of energy are a promising solution, but there are downsides too. The integration of renewable energy sources causes problems with the electric power systems, as their energy production is meteorologically dependent. In this paper a system is introduced that represents a solution to this problem, with the activation of users of the distribution part of the electricity network. The system connects the users of the distribution network that are willing to participate in the system environment based on market rules. The participation allows users to offer an adaptation of their consumption of electric energy or production in return for financial incentives. The system accepts or rejects the user's energy adaptation offers on the basis of market principles that are driven by the optimization method (genetic algorithms in the presented case). The system optimizes the total cost amount that is reflected in the integration of a larger portion of the renewable energy sources into the electric energy system. Testing the results of the system operation demonstrates that the developed solution has improved the integration of renewable energy sources and has enabled users to profit from their adaptation to energy consumption or production.

Keywords: renewable energy sources, smart grid, active customers, control, scheduling, optimization, genetic algorithms

0 INTRODUCTION

The European Union (EU) is encouraging the usage of renewable energy sources (RESss) (especially the usage of sun and wind energy) for two main reasons: a reduction in carbon-emission pollution and a reduction of the import dependence of the EU on foreign energy sources. However, the large proportion of RESs causes problems in electric power systems due to the stochastic nature of their primary power sources (e.g., sun and wind). In this way the power production of RES is dependent on the current meteorological situation, which causes problems in ensuring the energy balance between the production and consumption for electric power systems [1].

The integration of a larger proportion of RES into electric power systems therefore demands additional power plants to be built, just to ensure the energy balance in cases of sudden changes in the meteorological conditions. Taking into account these RES integration problems, their usage is not so efficient and offers an opportunity for the development of new solutions.

One technology that is promising more efficient RES integration is called "smart grid" and represents an upgrade of the current electric power systems. A smart grid is an electricity network that can intelligently integrate the actions of all the connected users in order to efficiently deliver a sustainable, economic and secure electricity supply [2]. Smart grids promise a more efficient RES integration with the participation of willing users that can control their electric energy consumption or production. It is to be expected that, in this way, it would be easier to maintain an energy balance for electric power systems.

The candidates for the corresponding users are mainly located in the distribution part of the electric network. They are the household consumers, industrial sector consumers, commercial buildings, distributed energy sources (small hydro and biomass power plants, etc.) and this also includes the development of new technologies, like energy-storage devices (electric cars and hydrogen fuel cells, etc.).

This participation of users involves three major changes to the network: the monitoring of all the users, the adaptation of the distribution part of electric network and the enhancement in the stability control of the electric power system.

Firstly, the monitoring of all the users, especially the RES electric energy production, enables the better stability control of the electric power system as it ensures the calculation of RES energy-production predictions [3]. Secondly, the production units, installed in the distribution part of the network, changes the network's energy flows and, as a consequence, an adaptation of the transformers, conductors and other elements has to be made in order to ensure that the newly installed capacities can deliver their energy to the network. And thirdly, the stability control with a voltage regulation and an energy balance has to be enhanced. Voltage control enables the appropriate voltage levels for all the users to ensure the adequate operation of their appliances [4] and [5].

---

*Corr. Author's Address: University of Ljubljana, Faculty of electrical engineering, Tržaška cesta 25, Ljubljana, Slovenia, marko.corn@inea.si

The energy balance between energy production and energy consumption ensures the stable and secure operation of the electric power system. Currently, the energy balance of the electric power system is only provided by a controlled energy production. With the introduction of smart grids, providing the energy balance may be expanded to all the users that are willing to participate in the balance process.

Users that are willing to participate can help to ensure the energy balance, either by the control of their electric energy consumption, by the control of their electric energy production or by a corresponding combination of both.

Firstly, the control of electric energy consumption means the control of the loads. One type of load is the household appliance, like washing machines, dish washers, etc. that can postpone their energy consumption. The second type are those that can act as a storage facility for storing the electricity in thermal or any other form, like electric heaters, cooling devices, etc. [6]. These technologies are known as demand-response systems and can shift in time their energy consumption to help achieve the energy balance [7].

Secondly, control of the energy production refers to small power-plant units, like small hydro power plants, biomass power plants and others that can control their energy production. Systems that merge several distributed energy producers into a larger one are also called virtual power plants [8].

Thirdly, energy-storage devices like electric cars, hydrogen fuel cells [9] and others can be included as users, whose consumption and/or production of electric energy can be controlled. They are often called producers/consumers or simply “pro-sumers”.

This paper focuses on solving the energy balance problem that emerges with the installation of RESs into electric power systems. The proposed solution describes all the important elements. In Section 1 the system that connects all the users participating in an energy-balance process is introduced. In Section 2 the developed simulation environment is presented, comprising a group of consumers, RES producers and users that participate in the energy-balance process. This environment was designed for testing and optimization purposes. In Section 3 the simulation results are presented, proving that the presented system successfully reduces the effects of RES integration and ensures the energy balance of the simulated group. Concluding remarks and plans for future investigations are explained in Section 4. The paper ends with a section that summarizes the used nomenclature.

1 SYSTEM FOR ENERGY BALANCING

In the electric energy market consumers are divided into balance groups that are connected through the power network with the producers of electrical energy. Balance groups are a collection of metering points (representing consumers and producers) used to calculate the balance between the consumption and production of electrical energy. With a larger amount of RES integrated into the balance group, achieving an energy balance is more difficult and more expensive. The presented system for energy balancing (SEB) fuses demand-response systems, virtual power-plant systems and the new pro-sumers [10] in order to minimize the cost of energy used to achieve the energy balance of a balance group. Fusion is realized with the implementation of an internal energy market that consists of market participants, market products and a market control algorithm.

1.1 Participants in the Internal Energy Market

The participants in the internal energy market represent all the users of the electric power system that have the capability to control their electric energy production or consumption and are also willing to participate. They all compete with each other to provide the energy that ensures the energy balance of the balance group. There are two types of participants: active customers and external participants.

Active customers are the users of the balance group that are willing to participate in the energy-balance process. The users of the electric power system that were used in demand-response systems, virtual power-plant systems and pro-sumers have become active customers in the internal energy market.

The external participants represent electric power producers that are not a part of the balance group but can provide the energy to achieve the energy balance. The first type of external participant is an organized electric market that is a central place where the supply and demand for electricity is faced. The second type of external participants consists of different electric energy producers that can provide energy to ensure the energy balance based on individual contracts. Both represent different options for ensuring the energy balance of the balance group with the main difference in the energy prices. In order to participate on the internal energy market all the participants must trade their energy in the form of energy products.

1.2 Products of the Internal Energy Market

The basic trading products in the internal energy market are offers of electric energy. There are two types of offers: flex offers and external offers. Flex offers are generated by the active customers and external offers are provided by the external participants.

1.2.1 Active Customers' Offers

The SEB connects all the active customers into an internal energy market using flex offers. A flex offer is an energy offer generated by the active customer that sends a message to the SEB with the information – how much, when, and for which price – about how the active customer is willing to consume or produce its electric energy [11]. The flex offer (O_{flex}) is defined by eight parameters, as indicated in Eq. (1). The parameters of the flex offer (they are illustrated in Fig. 1) describe the availability window, the duration window, the power window and the prices. The availability time window is defined by the interval ($t_{\min a}$, $t_{\max a}$), the duration interval ($t_{\min d}$, $t_{\max d}$) and the power window ($P_{\max}$, $P_{\min}$).

$$O_{flex} = \{t_{\min a}, t_{\max a}, t_{\min d}, t_{\max d}, \\ P_{\min}, P_{\max}, p_{pro}, p_{con}\}. \qquad (1)$$

They represent the flex offer's flexibility as they can be shifted in terms of availability time (indicated by index a), time of duration (indicated by index d) or electric power. The price parameters specify the financial incentive for the active customer's service.

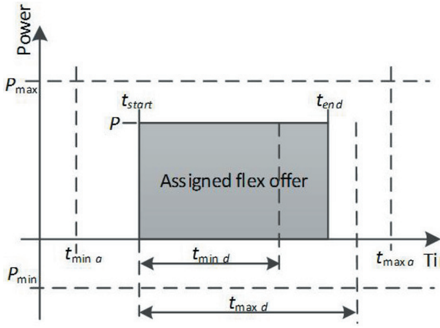

Fig. 1. *Example of a flex offer and assigned flex offer*

There are two types of prices in the flex offer, one for production (p_{pro}) and the other for consumption (p_{con}), because an active customer can offer both energy production and energy consumption at the same time and demands a different cost refund for the offered services.

If an active customer service is needed, the SEB assigns a flex offer, which means that the flex offer is set to an exact start time (t_{start}), end time (t_{end}) and power value (P) with the respect to the flex-offer limitations. An assigned flex offer can be seen in Fig. 1 as a grey square. The active customer will start to execute its service only if its assigned flex-offer start time is equal to the current time. With the start of the execution of the assigned flex offer the active customer gets its financial incentive.

1.2.2 External Participants Offers

An external offer (O_{ext}) represents the energy that can be purchased from the external participants and is defined with three parameters: start time ($t_{ext\ start}$), end time ($t_{ext\ end}$), and the price for the unit of electric energy (p_{ext}), as is indicated in Eq. (2):

$$O_{ext} = \{t_{ext\ start}, t_{ext\ end}, p_{ext}\}. \qquad (2)$$

Active customers compete with each other and with the external participants to provide the energy for achieving the energy balance of the balance group. This process takes place on the internal energy market that is driven by the internal market control algorithm.

1.3 Internal Market Control Algorithm

The market control algorithm, illustrated in Fig. 2, controls the active customers by optimizing the costs of the electric energy used to achieve the energy balance of a balance group, which is reflected in a more efficient RES integration and so enables the installation of a higher portion of RESs. In the first step the market control algorithm has to calculate the predicted energy imbalances ($E_{prd\ imb}$) of balance group:

$$E_{prd\ imb}(l) = E_{prd\ pro}(l) + E_{prd\ con}(l) + \\ + E_{prd\ ext}(l) + E_{prd\ AC}(l), \qquad (3)$$

where $l = 1, ..., m$ and m is prediction time.

The predicted energy imbalances are imbalances between the predicted energy production ($E_{prd\ pro}$), the predicted energy consumption ($E_{prd\ con}$), the energy purchased from external participants ($E_{prd\ ext}$) and the energy of the active customers ($E_{prd\ AC}$). An example of the predicted energy imbalances can be seen in Fig. 3. The energy from the external participants represents the energy that was purchased in previous iterations of the control algorithm's execution. The energy from the active customers represents the energy of the assigned flex offer that started to execute. In the next step the market control algorithm collects all the flex and external offers and it arranges them into a pool of offers.

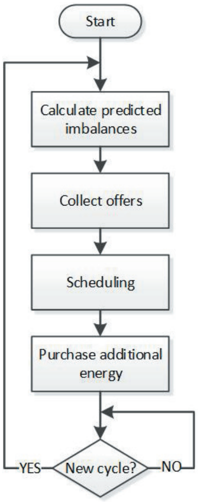

Fig. 2. *Steps of the internal market control algorithm*

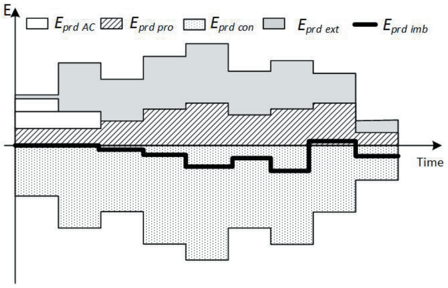

Fig. 3. *Example of predicted energy imbalances*

The process of choosing the optimal set of offers for energy balancing is carried out by the program part called the scheduler. This scheduler calculates which offers from the pool are the most appropriate for reducing the predicted energy imbalances. The scheduler assigns or rejects the flex offers and calculates the amount of energy that has to be purchased from external offers in such a way that the predicted imbalances are eliminated and the costs are minimized. The accuracy of the scheduler determines the cost reduction of the balance group and the benefits of the active customers. Optimization search space is discrete and its complexity rises with the amount of flex offers. For this type of problem, evolutionary-based algorithms have proven to be the right tool [12]. Their main advantage is that they are also very successful in the cases of complex problems with a large number of parameters to be optimized. For solving the presented problem a genetic-algorithm-optimization method has been chosen, with its implementation in the Matlab Global optimization toolbox [13]. The optimization fitness function (fit_{sch}) represents the SEB costs of balancing the energy, as indicated in Eq. (4):

$$fit_{sch} = \sum_{i=1}^{h} p_{i\,AC} + \sum_{i=1}^{m} p_{i\,ext}(i). \tag{4}$$

The fitness function is a sum of the energy costs of active customers and the energy costs of the external offers.

The last step is the purchasing of the scheduled external offer energies that the scheduler has calculated. The algorithm progresses with time by repeating the steps of prediction, scheduling and purchasing the energies.

The internal market control algorithm uses the internal energy market to face all the offers of energy and searches the cheapest way to minimize the predicted imbalances.

2 SIMULATION ENVIRONMENT

A simulation environment was developed for testing all the elements and activities that are important from the point of view of the balance group. It was implemented in Matlab [14], as this program offers efficient algorithm development and is supported by a range of toolboxes for different aspects of modeling and optimization. The balance group model consists of four elements: passive producers, passive consumers, external participants and active customers. They are illustrated in Fig. 4.

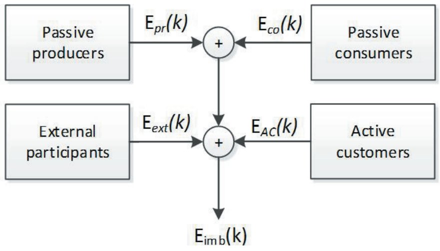

Fig. 4. *Balance group model*

The passive producer's element represents the electric energy sources that cannot adapt their energy production. The passive consumer's element represents all the consumers that do not adapt their energy consumption (households, industry, etc.). The external participant's element represents the external participants of the internal energy market and the active customer's element is the energy production or consumption derived from the active customers' services.

All four elements are connected with two discrete equations that describe the electric energy flow (E_{imb}) and the financial flow (C_{SEB}):

$$E_{imb}(k) = E_{pr}(k) + E_{co}(k) + E_{ext}(k) + E_{AC}(k), \quad (5)$$

$$\begin{aligned} C_{SEB}(k) = C_{pr}(k) + C_{co}(k) + C_{ext}(k) + \\ + C_{AC}(k) + C_{imb}(k). \end{aligned} \quad (6)$$

The energies of one interval (k) from all four elements are summarized and the difference between the production and consumption is equal to the imbalanced energy (E_{imb}). The earnings of the *SEB* (C_{SEB}) are equal to the *SEB* costs, which have to be paid to passive producers (C_{pr}), external participants (C_{ext}) and active customers (C_{AC}), with added *SEB* incomes charged to the passive consumers (C_{co}). The energy and the costs of the imbalances (C_{imb}) are always eliminated by the market control algorithm.

The presented model does not include a model of the electric power network, which can be carried out under the assumption that the elements included in the balance group are relatively close to each other and the transport losses of the energy can be omitted from the description. Each element in the balance group model generates the energy and financial flow that reflects its main operation.

2.1 Passive Producers' Model

The passive producers' model consists of the solar and wind power plants model. The combined energy production (E_{pr}) of the passive producer model is the sum of all the energy from the solar power plants (E_{solar}) and the wind power plants (E_{wind}):

$$E_{pr}(k) = \sum_{i=1}^{n} E_{solar\,i}(k) + \sum_{i=1}^{m} E_{wind\,i}(k). \quad (7)$$

The cost for the produced energy (C_{pr}) is the product of the produced energy and the corresponding price (p_{solar} for solar and p_{wind} for wind energy):

$$C_{pr}(k) = \sum_{i=1}^{n} E_{solar\ i}(k) \cdot p_{solar} + \sum_{i=1}^{m} E_{wind\ i}(k) \cdot p_{wind}. \quad (8)$$

The energy production of the solar and wind power plants is obtained from measurements of the corresponding power plants, which are then scaled down to meet the required energy for the simulated balance group [15].

2.2 Passive Consumers' Model

The passive consumers' model consists of several consumer types, like residential, industrial and business buildings, resulting in a total passive consumer's energy consumption (E_{co}):

$$E_{co}(k) = \sum_{i=1}^{n} E_{consumer\ type}(k). \quad (9)$$

The *SEB*'s income for the consumed energy (C_{co}) is charged regarding the contracted price of the energy (pcontract) between the *SEB* and the consumer:

$$C_{co}(k) = \sum_{i=1}^{n} E_{consumer\ i}(k) \cdot p_{contract\ i}. \quad (10)$$

For each of these consumers the energy-consumption profile was obtained from the measurements [15].

2.3 External Participants' Model

The external participants' model represents the electrical energy that is purchased from, or is sold to, the external participants. The SEB purchases electric energy from external participants if the predicted imbalances show a deficit in its energy balance and sell its energy otherwise. An example of the purchase and selling energy prices' time profile for the external participants is presented in Fig. 5.

The dynamic of the prices has its background in the energy production from different types of power plants. The most expensive energy is produced by gas power plants, as they have the shortest response time. The consequence is that they are listed closer to the current time and have the highest prices. By moving away into the future the response times of other types of power plants are getting longer and their costs are falling until they reach the prices of the cheapest power plants. The representatives of such power plants are nuclear, coal and other power plants with longer response times. They operate at nearly constant operating powers, where they have the highest efficiency and therefore the cheapest energy [16].

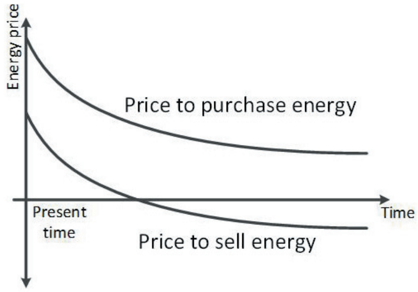

Fig. 5. *Energy prices from external participants*

2.4 Active Customers' Model

The active customers' model incorporates all the active customers of the balance group and describes their energy production or consumption (E_{AC}) and the corresponding costs for the *SEB* (C_{CA}):

$$E_{AC}(k)=\sum_{i=1}^{n}E_{ACi}(k), \tag{11}$$

$$C_{AC}(k)=\sum_{i=1}^{n}(p_{pro\,i}\ or\ p_{con\,i})(k). \tag{12}$$

Each active customer behaves as a separate object that messages its flex offers to the SEB and executes the results of the scheduler. After the execution of its service the active customer sends a new flex offer.

3 SIMULATION RESULTS

All the parameters that define the simulation environment are presented in Table 1. The simulation of the balance group was realized by using a group of 1000 household consumers with a total energy consumption of 25 MWh per day, which generates around 1950 € per day of income with the contracted price for consumer energy at 78 €/MWh [16]. The error in the predictions that are used to calculate the predicted energy imbalance (Eq. (3)) is dependent on the applied prediction method. As a calculation of the predictions is not within the scope of this paper, another approach was used. Because the simulation is based on the production of electric energy and consumption measurements, the prediction can be calculated as data distortion in a way that the desired error of the prediction is achieved. Fig. 6 shows an example of energy predictions. The calculation of predictions (data distortions) from measurements is made by randomly alternating measurements in such a way that at the present time the measurements are not distorted and with an increasing prediction time the distortion limits rise and at the maximum prediction time (m) the distortion ($e_{\max}$) can be achieved.

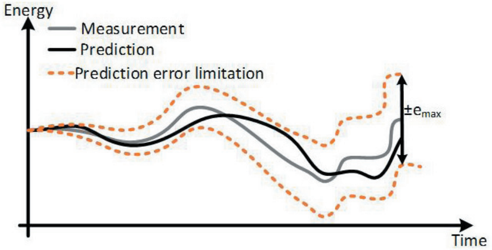

Fig. 6. Example of providing energy predictions from measurements

This means that the measurement data was randomly altered up to 10% of the original values. The value of the maximum prediction error was chosen on the basis of the error predictions of other methods that range from 5 to 20% accuracy [16].

Table 1. *Simulation parameters*

Prop.	Value	Description
n	24 h	Simulation time
m	12 h	Prediction time
t_s	15 min	Sampling time
e_{max}	10%	Maximum prediction error
$p_{pr\,max}$	150 €/MWh	Maximum price to purchase energy
$p_{pr\,min}$	50 €/MWh	Minimum price to purchase energy
$p_{co\,max}$	100 €/MWh	Maximum price to sell energy
$p_{co\,min}$	-10 €/MWh	Minimum price to sell energy
p_{res}	41 €/MWh	Price of energy from RES

The prices of the external energies reflect the prices of the energy produced by different types of power plants, from 150 €/MWh ($p_{pr\ \max}$) for most expensive gas-powered plants to 50 €/MWh ($p_{pr\ \min}$) for the cheapest nuclear-power plants [17]. The testing was divided into two parts. The first test shows the effects of RES integration on the SEB earnings, and the second test demonstrates how the usage of active customers reduces the effects of RES integration. The used parameters of the simulation are presented in Table 1.

3.1 Effects of RES Integration

The results of this test are illustrated in Fig. 7. They show how the RES integration affects the earnings of the SEB without the usage of active customers. The results also indicate a 1.7% increase of the costs for the SEB with every 10% of new RES installations, which corresponds to a 7% reduction of the SEB earnings for every 10% of the new RES installations.

The costs of the SEB presented in Fig. 7 consist of the cost of the purchased energy on the internal energy market and the cost of the RES energy.

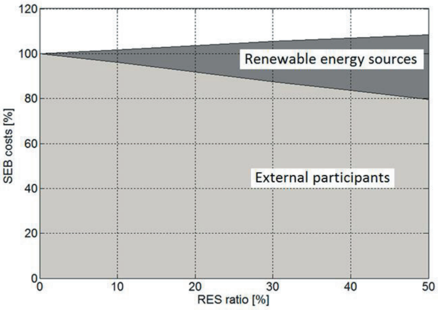

Fig. 7. *Effects of RES integration*

With the higher ratio of the RES the costs for the SEB are rising despite the fact that the RES energy costs less than the cheapest energy from the external participants. This is a consequence of the higher amount of RES energy production that influences the accuracy of the predicted imbalances. The reduction of the accuracy leads to a larger amount of energy purchased from the external participants. The results are used as a reference to compare them with the SEB capabilities of the RES integration.

3.2 RES Integration with Active Customers

The presented results reveal the the capabilities of SEB when it comes to reducing the effects of RES integration. It is divided into two tests. The results of the first test show the potential rise of SEB earnings without incentives to the active customers. The results of the second test show how the different prices of the active customer's services influence the SEB earnings.

3.2.1 SEB with Free Active Customers Services

The purpose of this test is to show how much the SEB can earn without incentives to the active customers. The maximum rise of the SEB's earnings demands the minimum price for the active customer's services. All the active customers have the same parameters for generating flex offers and are listed in Table 2.

An active customer flex offer consists of 20 kWh of energy, which in 24 hours of simulation time is offered 12 times. These settings bring a maximum of 240 kWh of flexible energy per active customer, which represents approximately 0.5% of the total energy consumption for one simulation run. The results of this test are presented in Fig. 8.

Table 2. *Parameters of AC energy offers*

Parameter	Value
[$t_{\min a}$, $t_{\max a}$]	[0, 5] h
[$t_{\min d}$, $t_{\max d}$]	[0, 2] h
[$P_{\min}$, P_{max}]	[-10, 10] kW
p_{pro}, p_{con}	0 €, 0 €

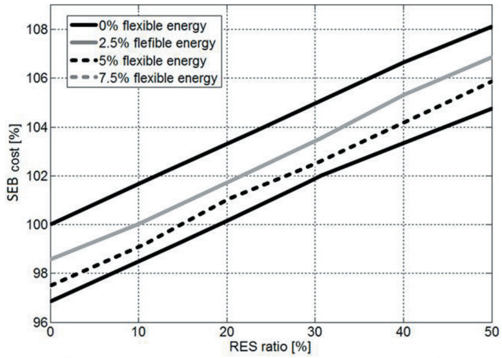

Fig. 8. *Dependence of the SEB costs from the RES ratio and active customer energy share*

The results show that the usage of active customers successfully reduced the costs for the SEB, which is reflected in higher earnings for the SEB. With the use of five active customers representing 2.5% of all the consumed energy it is possible to integrate 10% more RES, while the costs or the SEB's earnings stay the same. With an increase of the active customers' capacity, the SEB earnings per active customer are reduced because they are approaching the limit when the active customers are covering all the energy that has to be purchased to cover the predicted energy imbalances. The SEB's earnings created by using the active customer's services represent a profit that is shared with the active customers. The amount of the SEB's earnings is driven by the competition of the active customers' prices, assuming that the external participants do not change their prices.

3.2.2 SEB with Active Customers that Charge for Their Services

The presented results demonstrate how the different prices of the active customers' services influence the amount of SEB earnings. A test was performed at 20% of the installed RES (as this is also the goal of the EU to be fulfilled by 2020 [18]) and with 10 active customers, representing 5% of the flexible energy. The results are presented in Fig. 9 for the producer type of active customers and in Fig. 10 for the consumer type of active customers.

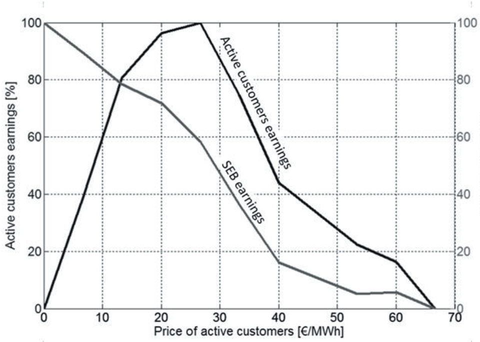

Fig. 9. *SEB earnings and active customer earnings for the producer type of active customers*

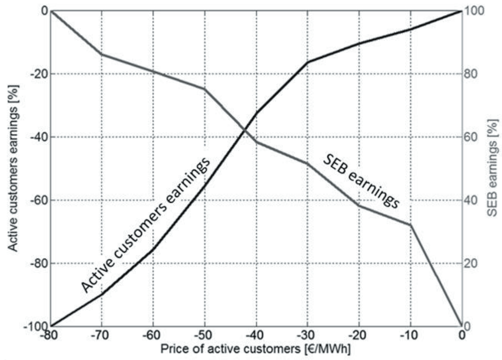

Fig. 10. *SEB earnings and active customer earnings for the consumer type of active customers*

The results in Fig. 9 shows that the initial earnings of the SEB group are dropping with an increase of the active customer’s prices. The earnings run dry when the active customer’s prices are higher than the external energy prices. The results in Fig. 10 show the earnings of the production active customers are rising with the rising prices and reach a peak at 28 €/MWh. Then they start to fall because the offered prices are getting closer to the external offer’s costs. The consumer types of active customers offer their energy consumption and are willing to pay for it as long as the difference between the contracted power price (78 €/MWh) and the offered price suits their economic eligibility.

4 CONCLUSION

This paper presents an effective solution for solving the energy-balance problem that emerges with the installation of *renewable energy sources* in electric power systems.

The results revealed two ways that the proposed SEB can increase its profit. The first possibility is to use the active customers to balance the predicted imbalances due to the changing predictions. In this case the active customers represent the stored energy that is always available to the balance group. This energy costs nothing as it waits to be used in contrast to the balance group with no active customers, where in such situations it is necessary to purchase energy from external participants for the compensation of the error in the predictions. The second way to increase the profit is to purchase cheaper energy for the active customer’s services that is available on the internal energy market for more distant times in the future.

The SEB (besides the improvement in the RES integration) also opens a whole new market for active customer’s services that can profit from it. The earnings of the active customers depend on the market competition and the results show that it is possible for the active customer to sell energy production for 60 €/MWh and purchase energy for 10 €/MWh. The active customer’s prices are always limited at the top end by the short-term energy prices from external participants and limited at the bottom end by the economic eligibility of its service.

From the perspective of energy management in the electric power system the SEB can offer a solution for more efficient RES integration of the balance group. It is particularly suitable for small communities or for helping to reduce the costs of infrastructure investments for the electric power system’s operators by distributing the energy peaks of a part of an electric network.

The presented solution of integration does not explicitly take into account the energy losses because of the energy transportation and the problems regarding the stability control that can arise from the changes in the energy flows for the distribution network. Our future investigations will also be directed to studying the possibilities to include a more advanced power system model that will include the grid constraints like limited capacities and transport losses, which would bring the SEB to more widespread use.

5 NOMENCLATURE

O_{flex}	Flex offer
$t_{min\ a}$, $t_{max\ a}$	Availability window of the flex offer
$t_{min\ d}$, $t_{max\ d}$	Duration window of the flex offer
P_{min}, P_{max}	Power window of the flex offer
p_{pro}, p_{con}	Production and consumption prices of the flex offer
t_{start}, t_{end}, P	Parameters of the assigned flex offer
O_{ext}	External offer

$t_{ext\ start}$, $t_{ext\ end}$	Time window of external offer
p_{ext}	Price of the external offer
$E_{prd\ imb}$	Predicted energy imbalance
$E_{prd\ pro}$	Predicted energy production
$E_{prd\ con}$	Predicted energy consumption
$E_{prd\ ext}$	Energy purchased from external participants
$E_{prd\ AC}$	Energy purchased from *AC*
fit_{sch}	Fitness function of scheduling algorithm
E_{pr}	Energy from producers
E_{co}	Energy to consumers
E_{ext}	Energy from external participants
E_{AC}	Energy from *AC*
E_{imb}	Energy imbalance
C_{SEB}	Earnings of system for energy balancing
C_{pr}	Costs of energy for producers
C_{co}	Income for energy for consumers
C_{ext}	Cost of energy for external participants
C_{AC}	Cost of energy for *AC*
C_{imb}	Cost of energy imbalances
E_{solar}, E_{wind}	Energy from RES
p_{solar}, p_{wind}	Price of RES
$p_{contract}$	Contracted price of energy for consumers

6 REFERENCES

[1] Miller, N., Manz, D., Johal, H., Achilles, S., Roose, L., Griffin, J.P. (2010). Integrating High Levels of Wind in Island Systems: Lessons from Hawaii. *Proceedings of 2010 IEEE International Conference on Sustainable Energy Technologies*, p. 1-8, Kandy, DOI:10.1109/ICSET.2010.5684403.

[2] Momoh, J. (2012). *Smart Grid: Fundamentals of Design and Analysis*. John Wiley & Sons, New Jersey, DOI:10.1002/9781118156117.

[3] Anvari Moghaddam, A., Seifi, A.R. (2011). Study of forecasting renewable energies in smart grids using linear predictive filters and neural networks. *IET Renewable Power Generation*, vol. 5, no. 6, p. 470, DOI:10.1049/iet-rpg.2010.0104.

[4] Kolenc, M., Papič, I., Blažič, B. (2012). Minimization of losses in smart grids using coordinated voltage control. *Energies*, vol. 5, no. 10, p. 3768-3787, DOI:10/3390/en5103768.

[5] Uljanić, B., Pfajfar, T., Papič, I., Blažič, B. (2012). Voltage control in distribution networks with distributed generation. *Journal of Electrical Engineering and Computer Science*. vol. 79, no. 3, p. 81-86.

[6] Krese, G., Prek, M., Butala, V. (2012). Analysis of building electric energy consumption data using an improved cooling degree day method. *Strojniški vestnik – Journal of Mechanical Engineering*, vol. 58, no. 2, p. 107-114, DOI:10.5545/sv-jme.2011.160.

[7] De Jonghe, C., Hobbs, B.F., Belmans, R. (2012). Optimal Generation Mix With Short-Term Demand Response and Wind Penetration. *IEEE Transaction on Power Systems*, vol. 27, no. 2, p. 830-839, DOI:10.1109/TPWRS.2011.2174257.

[8] Hernandez, L., Baladron, C., Aguiar, J., Carro, B., Sanchez-Esguevillas, A., Lloret, J., Chinarro, D., Gomez-Sanz, J.J., Cook, D. (2013). A multi-agent system architecture for smart grid management and forecasting of energy demand in virtual power plants. *IEEE Communications Magazine*, vol. 51, no. 1, p. 106-113, DOI:10.1109/MCOM.2013.6400446.

[9] Pregelj, B., Vrečko, D., Jovan, V. (2011). Improving the operation of a fuel-cell power unit with supervision control – A simulation study. *Journal of Power Sources*, vol. 196, no. 22, p. 9419–9428, DOI:10.1016/j.jpowsour.2011.06.077

[10] Corn, M., Černe, G., Atanasijević-Kunc, M. (2012). Balance Group Model with Smart Grid Elements. Proceedings of 7th Vienna Conference on Mathematical Modeling: MathMod 2012, p. 1195-1200, Vienna, DOI:10.3182/20120215-3-AT-3016.00212.

[11] Marinšek, Z., Černe, G. (2009). Roles and processes model for electricity market trading processes in Europe. *Proceedings of 6th International Workshop on Deregulated Electricity Market Issues in South-Eastern Europe*, p. 1-7, Bled.

[12] De Jong, K. A. (2006). *Evolutionary computation: A Unified Approach*, 1st ed. MIT Press, Cambridge.

[13] *Global Optimization Toolbox User's Guide R2013b*. (2013). The MathWorks, Natick.

[14] Matlab Getting Started Guide R2011b. (2011). The MathWorks, Natick. Micro Request Based Aggregation, Forecasting and Scheduling of Energy Demand, Supply and Distribution: Work package 6 – Trial Test Integration & Validation from *http://www.mirabel-project.eu/* accessed at: 2013-12-11.

[15] Wissel, A.V.S., Rath-Nagel, S., Blesl, M., Fahl, U. (2008). *Stromerzeugungs- kosten im Vergleich*. Institute of Energy Economics and the Rational Use of Energy, Stuttgart. (in German)

[16] Shuxia, Y. (2007). Power Consumption Forecast by Combining Neural Networks with Immune Algorithm. *8th ACIS International Conference Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing*, p. 238-241, Qingdao, DOI:10.1109/SNPD.2007.49.

[17] An Energy Policy for Europe (2007). Commission of the European Communities from *http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52007DC0001:EN:NOT*, accessed on: 2013-01-25.

[18] An Energy Policy for Europe (2007). Commission of the European Communities from *http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52007DC0001:EN:NOT*, accessed on: 2013-01-25.