УДК 621.31

P. Sokolovskyi., PhD student, **ORCID** 0000-0002-0113-4479
National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Kyiv, Ukraine
R. Sharma, PhD, Assoc. Prof., **ORCID** 0000-0003-4260-1130
University of South–Eastern Norway, Porsgrunn, Norway

ESTIMATION OF PV SYSTEMS POWER PRODUCTION EFFICIENCY IN THE DENSE URBAN DEVELOPMENT CONDITIONS

The paper describes the preconditions for planning and building an intelligent community of Energy Smart Community. The state of RES sector development, namely, PV stations in the energy structure of the United Energy System of Ukraine, has been characterized. The features of building an Energy Smart Community architecture include an analysis of the possibilities of joining their own generating capacities as an energy component in this system. The energy and economic criteria for such type of intelligent community are described. The article analyzes the foreign experience in building and implementing Energy Smart Community in power systems on the basis as pilot projects NYSEG and SCA for its further scientific research and testing. Using the software module in the Matlab Simulink environment, we have constructed and described the work on the example of an arbitrary PV module, with its principal dependencies being distinguished from the generalized solar insolation index. The obtained data point to all the prerequisites for the possibility of widespread participation of private PV systems of power supply as the main asset of the Energy Smart Community.

Keywords: Energy Smart Community (ESC), Smart City, Smart Grid, Demind – Side Management (DSM), Energy Storage Systems (ESS), photovoltaic (PV), Virtual Power Plant (VPP), renewable energy sources (RES), prosumage, Solar Power Plant (SPP), distributed energy resources (DERs), Energy Storage System (ESS).

Introduction. Modernization and development of renewable energy, laying the foundation for its functioning, the concept of Smart Grid main provisions, encourage the study of new directions in the energy sector. Today, the use of distributed energy sources is a priority on the way to the energy independence of many countries of the world. Accelerating the implementation of Smart City, Virtual Power Plant, and Microgrid networks concepts requires research to build not only from the point of the energy component view but also considering environmental and socio-economic directions [1, 2].

Photovoltaic (PV) systems promote to increase the share of electricity production by minimizing environmental problems and applying different economic incentives for their implementation [3]. In Ukraine, solar energy is most actively implemented both on an industrial scale and among private users, due to the launch of "green tariffs" in 2008 (effective until 2030) and adoption of the bill on the transition to a new mechanism for stimulating the introduction of "green projects - auctions", as well as improvement of the investment program from partner countries in the field of development of "Green technologies" [4, 5].

According to the National Energy and Utilities Regulatory Commission (NEURC), in the first quarter of 2019, 862 MW of generating capacity was put into operation, which exceeds the capacity put into operation for the whole year 2018 (848 MW). As of April 1, in 2019, the total capacity of the RES objects put into operation was 3,166 MW. PV objects from the total volume of RES are 2070 MW (66%). Of these, 1550 megawatts account for 7550 private households [6].

The introduction and changes PV systems in consumer and economic thinking have led to the emergence and functioning of consumer models such as prosumer and prosumage in the energy system of Ukraine. This is a prerequisite for changing the basic strategy for the functioning of the energy systems and the energy market, creating new formats of interaction within the "consumer-power supply company", described in the concept of Energy Smart Community (ESC) [7].

The main objective of the ESC is to increase the use of energy on the customer side and to stabilize the work both small and regional distribution systems. As an example, the daily schedule optimization of electrical survival: reducing the power shortage in peak hours, and reducing undervalued electricity volume in the hours of "night dip", etc. The ESC concept, due to economic incentives, consumer behavioral flexibility, and the deployment of Distributed Energy Resources (DERs) and key elements in the Smart Grid technology concept, implies a gradual decrease in energy dependence from traditional energy sources. The main role in the ESC is given to the consumer investor awareness development, namely: the use of integrated system planning for the transition to effective business models in the energy sector [8].

An example of building a smart community is a pilot project, developed and implemented by the New York State Electric and Gas (NYSEG) project for exploring the potential of using smart meters and other modern technologies for upgrading energy networks. The 12400 electricity consumers in New York's Tompkins County receive the most accurate energy consumption figures data for a better understanding of their own energy consumption. Through the online software tool, access through real-time energy consumption data, power consumption warning, and power saving advice is provided through an individual access channel [9].

Another example is an autonomous power supply system built on the island of Aruba (South Caribbean). Independent energy community – Smart Community Aruba is provided on the basis of 20 buildings located in the same neighborhood (put into operation in 2017). Thanks to the tropical climate and solar activity of more than 2000 hours, and each solar power plant placement, one of the largest test stands has been built, which based on the demonstration and verification of issues are: PV systems stability, consumer behavior studies, waste issues, energy storage, and rational use in accordance with tariff policy. According to the project, it is planned to move the entire island's grid to Smart Community Aruba by 2030. At present, the combination of 20 buildings, combined with a single Smart Grid system, serves to attract investment and to check various technical and economic parameters [10].

The purpose of the work is to analyze the planning, construction, and operation of the Smart Community ESC and the peculiarities of its adaptation to the conditions of the Ukrainian energy sector development.

The main prerequisites for building the concept of Energy Smart Community.

For energy companies, one of the most pressing issues for today is the question of how to actively influence and/or respond to changes in the industry: to organize change management, actively participating in shaping their own future, or take a passive position.

Among the most significant changes in the development of society and the economy, which affect the energy industry, including the following criteria:

1. The shortage of shunting sources of electric power generation.

2. Constantly growing demands for reliability and quality of electricity supply to/from consumers, which, according to experts, in some cases, are overestimated. Not so long ago, the question of electricity supply quality was a problem only for certain categories of large industrial consumers. Today, the problem of high-quality power supply already affects all consumers: the population and communal consumers express concern, caused by emergency shutdowns, which demonstrate the insufficiently high quality of power supply. In the next 20 years, the quality of electricity will be the biggest problem in the industry [11].

3. Continuous increase in the cost of electricity around the world: despite curbing electricity tariffs policy.

4. Aging and the growing shortage of skilled human resources in the energy sector and public awareness.

5. Growth of Prosumers' stakeholder requirements to energy companies performance.

Consumer model "Prosumer" (from professional or producer + consumer - "professional consumer" or "producer-consumer") is a person or object that actively participates in the production process, conversion, distribution and consumed electricity [12]. The change in organizational forms of ownership and the market formation conditions led to a new requirements system emergence of for individual energy market players for the energy companies. Which is essential to increase the electricity supply reliability reduce operating costs, increase the income of investors, reduce the number of staffs, and so on.

6. Ecological and industrial requirements safety of the functioning of energy objects.

The above requirements (1–5) affect both the power generation and the activities of electricity and distribution companies serving as the main players that balance demand and supply. The results of this influence are manifested in climate change and global warming, growth of losses to third parties and the environment, natural resources pollution and depletion, increase of investment risks, etc.

7. Reducing system-wide costs. In its current state, most of the trunk and dispersed networks are not able to ensure the efficient a large number of small power plants (distributed generation) connection, including those operating on renewable energy sources.

Energy Smart Community in the building of modern Smart Power Systems.

An increase in the number of distributed energy sources in the system can lead to the stability breach of the power system. The combination of information and energy flows facilitates the transactional processes that carry out highly coordinated self-optimization and the ability for retail customers to effectively participate in energy and energy purchase and sale mechanisms. Thanks to the introduction of all power supply system elements by smart modules and interface switching channels, it enables the highest level of synchronization in real time between the information exchange center and the consumer [13–14]. This approach will track the energy and financial flows of end-users through Smart House systems and management systems based on key tools for monitoring, controlling and optimizing energy use, and managing information flows [15].

The Smart Community strategy as one of the key components of the transition to Smart Grid and Smart City involves sharing by geo-location location participants, communities in the urban environment, suburbs and the private sector. This division is explained by different characteristics: electricity consumption, socio-economic differences, the density of development, private availability and/or collective generating systems.

In this paper, research on the efficiency of using private PV to cover private home energy needs of a was conducted. The choice of research objects is explained by switching possibility from energy-dependent general networks to work of the community an autonomous model.

ESC optimizes the work of a local power company, which can affect the stable operation in the power distribution system and the entire power system. Examples of implementing the interaction of the concept of ESC with other Smart energy systems are described in [16].

In fig. 1 shows the block diagram of the ESC network project.

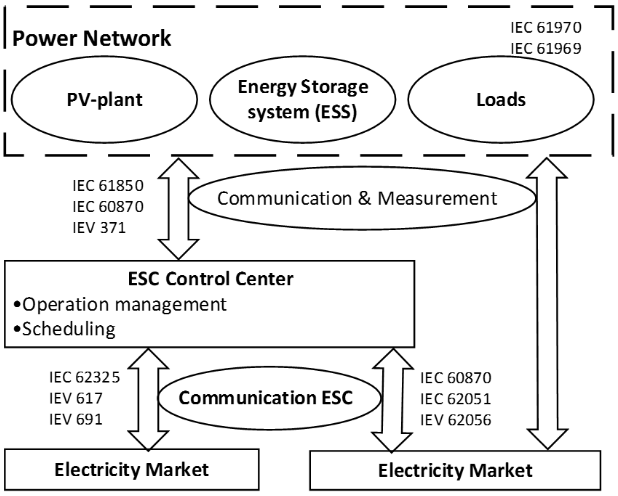
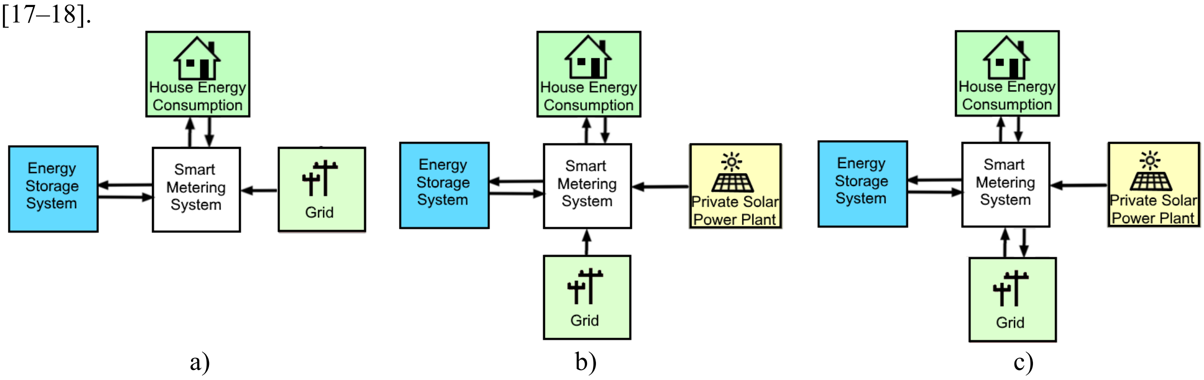


Figure 1– ESC components and influencing factors

Where on fig. 1are standard, which are bases in building ESC: telecontrol – IEC 60870, IEV 371; communication systems in substations – IEC 6185; interface for distribution management – IEC 61968;

Energy market communication – IEC 62325; data exchange with metering equipment / electricity metering – IEC 62051 /IEC 62056; application in energy management system - IEC 61970 / 61969

Consumer Energy Modes in the Energy Smart Community structure. It is advisable to distinguish between three operation modes of households, characterized by the presence by private PV stations and/or the storage of electric energy (Fig. 2), which shows three main modes of energy supply systems functioning at home [17–18].



a) electricity consumption from the network; b) consumption with PV system + network; c) Prosumage mode (the arrows indicate the direction of the power flow) [17].

Figure 2 – Operating modes of local power supply systems with PV systems.

On Fig. 2,a while electricity consumption from the grid is presented – the base model (consumer model) is characterized by the use of ESS systems to cover peak energy needs hours and tariff incentives for energy as efficient incentives for energy saving and minimizing the cost of purchasing electricity for two- and three pond rates tariff. PV system + network consumption – describes the process of maximizing own electricity consumption from the PV station and minimizing network consumption (Prosumer) Fig. 2, b.

Prosumage mode (Fig. 2, c) describes private households with RES systems that work both for electricity consumption from the network and for its sale at the green tariffs [4], in order to maximize revenue. This regime is an example of future energy changes and requires local energy modernization infrastructure and control systems. This mode is characterized by minimal self-generation limitation and consumption from the network at the expense of the electric energy storage device, where the consumer is simultaneously a regulator. Considering full future Ukraine's power grid transition to the auction system for purchasing electricity from renewable sources, this model is most adapted due to its flexibility. The Prosumage active development in the mid-2020s is projected as a result of a reduction in cost savings systems (Energy Storage System – ESS).

In the first and second modes shown in Fig. 1, and the same Fig. 1, b., Prosumers, which reacts and influences the energy market through systematic actions and reactions aimed at minimizing costs and increasing own (and / or) collective returns. In the third mode, prosumage is a full-fledged market participant and can handle the energy generated by selling it in the electricity market at the most favorable prices. Between all structural elements of the scheme, the exchange of information on the level of consumption and generation in online mode [19].

Each of the three models can be involved in planning and constructing the Energy Smart Community's operation model, but the scenarios for their work and the boundary conditions for their involvement in energy and energy planning.

Planning and managing demand in the Energy Smart Community network.

The use of consumer demand management mechanisms overlaps Demand - Side Management (DSM) in an ESC environment built on the technical Microgrid or VPP concept provisions, mainly focused on optimal load planning of individual consumer groups, with respect to changing tariffs over the day course and considering consumer the consumers activity [20 – 21]. The re-qualification of electric energy consumers into the model agents consumer dictates the need to revise approaches to the management in the energy sector: a reorientation from Supply Chain Management - a concept focused on managing the producer companies costs - to Demand Chain Management - a concept based on the direct consumers involved in the process creating value. In the electric power industry, the basis for such re-training is the formation of a customer-oriented the electricity market model, based on the integration of prosumers and prosumage into the organizational and economic relations system [18, 22].

The emergence of Prosumer - Side Management (PSM), which based on principles of are partly duplicated by DSM, but differ in more flexible possibilities for customization set under changing network conditions. PSM is managing micro-intelligent networks way in a much more complex, volatile and energy market in real-time, controls and managers entrusted to Smart Agents. Smart Agents provide functions for controlling electricity consumption, managing and planning energy and economic activities. In the role of Smart Agents can act as consumers of three types (consumer, prosumer, prosumage), as well as intermediary companies or management companies. [23 – 25].

Prosumer - Side Management interacts with a power supply company based on a partnership agreement and integrates both ordinary consumers, both prosumer and prosumage, by advising on the energy efficiency of an individual entity or object of this energy association. The Smart Metering system allows you to accurately monitor and monitor the volume of electricity consumption and generation.

DSM and PSM should consider the availability of private sources of dispersed generation and ESS, with the limited generation prediction and accumulation of electricity due to limited weather forecasting. Therefore, it is advisable to link ESC's work with Microgrid and Virtual Power Plant's current decentralized power systems. The main task of optimization is minimizing the electricity use from the grid, and maximizing the attraction of electricity from its own generating sources.

The main expressions of the optimization task are defined as: W_G − generation volume, W_S − consumption volume, W_{RES} - generation volumes of RES, W_B − centralized generation volume. Time: $T = \sum_{j=1} t_j$;

Functioning of the system is described by the formulas for selecting electricity from sources [11]

$$W_G = \sum_{j=1} W_{G,j} \; ; W_{RES} = \sum_{j=1} W_{RES,j} \; ; \; W_B = \sum_{j=1} W_{B,j} \; ; \tag{4}$$

The following formula explains the purpose of the analysis, namely, minimization of power take-off from the main source of power supply and maximization of consumption with SPP:

$$W_{G,j} = W_{B,j} \cup W_{RES,j} \Rightarrow W_{B,j} + W_{RES,j} \; ; \tag{5}$$

The second goal is the calculation is to maximize the coverage of own needs at the expense of SES: $W_G \approx W_S$.

Therefore, we write for this condition (8):

$$\| W_S - W_G \| \le \delta_W \ , t \in [0, T] \tag{6}$$

The formula describes consumption volumes without optimization: $W_S^{**} = \sum_j W_{S,j}^*$. For the optimization condition, we write down $W_S = \sum_j W_{S,j}$ the condition where the demand management on the consumer side DSM appears:

$$W_{S,j} = W_{S,j}^* \cup W_{DSM,j} \Rightarrow W_{S,j}^* - W_{DSM,j} \tag{7}$$

DSM management provides optimal consumer-side consumption: $W_{DSM} = \sum_j W_{DSM,j}$.

Terms of minimization of consumption and from the network is described by the formulas:

$$\sum_j W_{B,j} \to W_{B,\min} ; \sum_j W_{S,j} \to W_{S,\min} ; \tag{8}$$

Terms of maximizing consumption from SES and using the demand management program is described by the formulas: $\sum_j W_{DSM,j} \to W_{DSM,\max} ; \sum_j W_{RES,j} \to W_{RES,\max}$;

The optimization task described by formula (11) explains the most optimal version of our system's operation, when own generation covers the maximum consumption, but the energy loss does not consider the problem:

$$\left(W_S^{(t)} - W_G^{(t)} \right) \Big|_{t \in [0,T]} = 0 , \tag{9}$$

Considering these principles, it is possible to adapt them to the implementation of a future system based on PV modules, for the following conditions:

1) economically oriented: maximizing profits due to optimal energy sales on the electricity market.

2) technically oriented: loyalty to own consumption during the day and system maintenance maximization, including the reserve of energy maximization and re-shipping maximization to the market.

$$\begin{aligned} \max f(p) &= p_{pv}(t) \cdot P_{pv}(t) + p_{continious,IH,T}(t) \cdot P_{pv,continious,IH,T}(t) + \\ &+ p_{SCR,pos}(t) \cdot P_{SCR,pos}(t) + p_{SCR,neg}(t) \cdot P_{SCR,neg}(t) + \\ &+ p_{MCR,pos}(t) \cdot P_{MCR,pos}(t) + p_{MCR,neg}(t) \cdot P_{MCR,neg}(t). \end{aligned} \tag{10}$$

The main constraints are:

1) The profit calculation which based on income (r) depends on the option of selling in the market and costs (c) (energy costs, sales on the mortgage market).

$$p_{pv}(t) = -c_{pv}; \tag{11}$$

$$p_{continious,IH,T}(t) =_{continious,IH,T} (t) - c_{continious,IH} . \tag{12}$$

Minimum possible generation for PV, which can be used for optimization: wind coefficients, $f_{pv,\min}$ set the lower limit of the minimum generation output. They determine the process-dependent output process. The default value for PV is zero.

$$f_{pv,\min} \cdot P_{pv,forecast}(t) \le P_{pv}(t). (13)$$

The maximum possible control is that the continuous presence control reserve for specified periods (continuous control of the monitoring reserve during the day, SCR-LT intervals, SCR-HT, MR-4-hours) and the prospecting of the PV are continuous.

Primary control reserve (PCR): positive and negative.

$$P_{PCR}(t) \le P_{pv,forecast}(t) - P_{pv}(t)\ ; \tag{14}$$

$$P_{PCR}(t) \le P_{pv,}(t) - f_{pv,\min} \cdot P_{pv,forecast}(t)\ . \tag{15}$$

Secondary control reserve (SCR): positive and negative

$$P_{SCR,pos,HT}(t) + P_{SCR,pos,NT}(t) \le P_{pv,forecast}(t) - P_{pv}(t)\ ; \tag{16}$$

$$P_{SCR,neg,HT}(t) + P_{SCR,neg,NT}(t) \le P_{pv}(t) - f_{pv,\min} \cdot P_{pv,forecast}(t)\ . \tag{17}$$

Minute reserve (MR): positive and negative:

$$P_{MCR}(t) \le P_{pv,forecast}(t) - P_{pv}(t)\ ; \tag{18}$$

$$P_{MCR}(t) \le P_{pv}(t) - f_{pv,\min} \cdot P_{pv,forecast}(t)\ . \tag{19}$$

Avoidance of multiple users to provide power control reserve: This limit determines the upper limit for the amount of control reserve that does not exceed the available power amount. This is divided into a positive and negative control reserve.

$$CR_{pos}(t) = P_{PCR}(t) + P_{SCR,pos,HT}(t) + P_{SCR,pos,NT}(t) + P_{MR,pos,4h-slice}(t)\ ; \tag{20}$$

$$CR_{pos}(t) \le P_{pv,forecast}(t) - P_{pv}(t)\ ; \tag{21}$$

$$CR_{neg}(t) = P_{PCR}(t) + P_{SCR,neg,HT}(t) + P_{SCR,neg,NT}(t) + P_{MR,neg,4h-slice}(t)\ ; \tag{22}$$

$$CR_{neg}(t) \le P_{pv}(t) - f_{pv,\min} \cdot P_{pv,forecast}(t)\ . \tag{23}$$

Minimum rate and increment for provision of control reserve according to market constraints: The control reserve amount can be equal to zero or a whole number, multiplied, depending on the minimum bid size and the minimum increase. The limit is presented for the primary control reserve with analog constraints for the secondary control reserve and for the remaining minutes.

The factor *y (t)* is a binary variable to prove whether enough energy is available to provide a management reserve.

$$P_{PCR}(t) - y_{PCR}(t) \cdot P_{PCR,\min}(t) \ge 0\ . \tag{24}$$

Restrictions on the wholesale market: According to the options discussed in this document, there is an opportunity to sell energy at the "Forward" auction, which is offered in an hour or on an uninterrupted market of the internal day offered for 15 minutes. Due to the fact that this is a planning process for the "Day ahead", market prices during the day should be considered predictable. The further limitation is that available energy should be sold on favorable terms.

$$P_{PV}(t) = P_{PV,auc}(t) + P_{pv,continious,IH,T}(t). \tag{25}$$

This methodology allows the economically optimal schedule of the day ahead, regardless of the ESC size (available power units) and the impact on the power system. In future systems with a high penetration of RES, this can lead to unstable effects and system services lack. Thus, the system itself and the operator of the ESC system need system support services to handle exemplary large generation and forecast errors.

ESC technology is considered as one of the most adapted to aggregate PV systems resources at the private and commercial levels [3]. In the traditional VPP, the central authority, that is, the VPP operator (OVPP), is responsible for controlling the energy of Microgrid. MGO minimizes the cost of both distributed energy resources and the purchase of energy from the utility network, and end users typically act as passive entities provided by the microenvironment [4] [5]. Recently, the Microgrid structure being built consists of multiparty attracted more attention. The parties may include Distributed Energy Resources (DER), active end-users with flexible workloads, search users, etc. which are considered independent entities with rationality and autonomy. Therefore, when the

Microgrid architecture becomes more and technologically more complex, different parties may have different goals for the purchase, sale or electricity consumption on their own, thus the purpose of energy management is to minimize their operating costs.

Modeling the effectiveness of PV panels

The base PV model of the panel is shown in Fig. 3. One-diode model of the photovoltaic panel is represented by a photocurrent and a diode, connected to the successive and shunt supports [25].

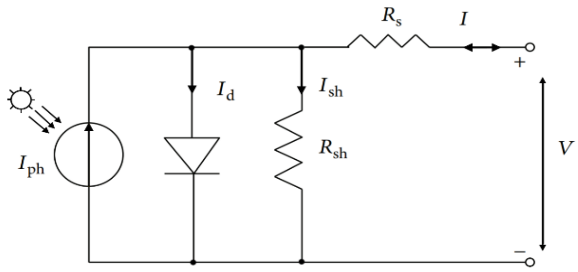


Figure 3 – PV panel equivalent circuit

The main parameters of the base PV model panel electrical circuit can be described by the following formulas:

$$I_{PV} = I_{ph} - I_s\left(\exp\frac{(V + R_s I)}{AV_T} - 1\right) - \frac{(V + IR_s)}{R_{sh}}; \tag{26}$$

$$I_{ph} = I_{sc} + K_i \Delta T \frac{G}{1000}; \tag{27}$$

$$I_s = \frac{I_{sc} + k_i \Delta T}{\exp(q((V_{oc} + k_{oc}(\Delta T / AV_T)) - 1}; \tag{28}$$

$$V_{PV} = V_i + k_V T_{PV}; \tag{29}$$

$$P_{PV} = N \cdot FF \cdot U_{PV} I_{PV}; \tag{30}$$

$$FF = \frac{I_{MPP} V_{MPP}}{I_i V_i}. \tag{31}$$

Where in equation (26): I_{PV} is output current of the panel (A), I_s is diode saturation current (A), I_{ph} is panel photocurrent (A), V is output voltage of the panel (V), A is diode's ideality factor, $V_T = N_s KT/q$ is the thermal voltage of the array with N_s cells connected in series (K is Boltzmann constant (J·K^{-1}), T is the temperature of the p–n junction, (K), q is electron charge (C))), R_s is series resistance (Ω), R_{sh} is shunt resistance (Ω).

In equation (27) I_{sc}: is the short-circuit current (A), $\Delta T = T - T_n$ (T and T_n being the actual and nominal temperatures (K), K_i the short-circuit current/temperature coefficient (K), G is solar irradiation (W/m^2).

Equation (28) is include in the equation the current and voltage coefficients k_i and k_{OC}; V_{OC} is open-circuit voltage (V).

In equation (29) V_i is idle voltage k_V current-temperature coefficient, (A/^{0}C), T_{PV} is the actual temperature on the sensor of the PV module.

In equation (30) P_{PV} is output active power of the panel (Watt), FF − full factor coefficient; V_i is idle voltage; short circuit current o; k_V current-temperature coefficient, (A/^{0}C), T_{PV} is the actual temperature on the sensor of the PV module.

In equation (31) V_{MPP} is the voltage when searching for max (V) (MPPT − Maximum power point tracker); I_{MPP} is the current when MPPT (A) [26].

Therefore, in this paper, the effect of these parameters on the output panel parameters is investigated (Fig. 4).

Calculation of the solar power plant allows you to predict with high accuracy the generated volumes electricity by photo modules for the given climate specific locality conditions.

The Matlab software has enough ready-made elements in the archive of the built-in library, but they only show the general parameters. Therefore, considering the research results, for the illustration of the efficiency of the proposed complex, a simple model of the PV module, the construction of which in the Matlab Simulink environment is shown in Fig. 4. Also, the experimental scheme involves studying the electricity generation by the PV panel, depending on the uneven solar insolation distribution on the panel itself surface, based on the shading level of the PV module buildings. The system builds output volt-ampere characteristics considering this indicator.

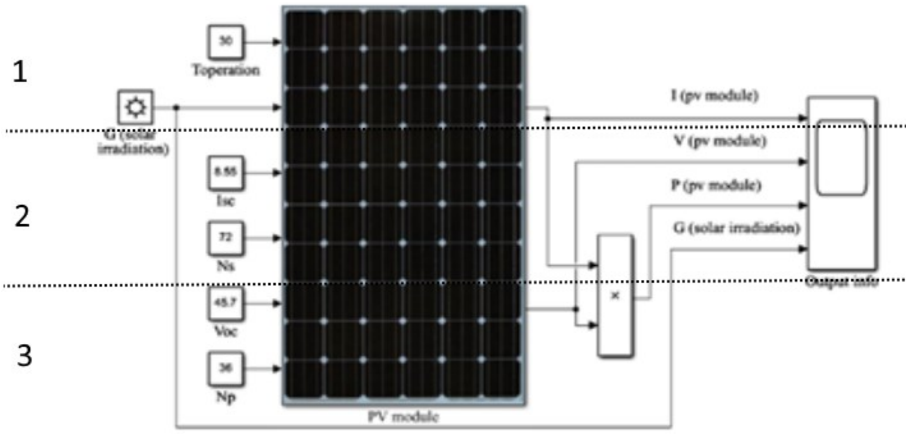


Figure 4 – PV panel Simulink model

The PV work systems require functioning analysis of PV modules different types, due to differences in materials and production technologies, as well as in operational differences. Therefore, in the simulation in the software environment, Matlab Simulink has been built universal PV program module. For further calculations, the Sundragon Model I300-72P [21] panel is selected, the main characteristics of which are given in the library of modules Simulink. It should be noted that such additional characteristics as photocurrent, diode saturation current, shunt and resistor resistance, as well as the coefficient of perfectness are not given. The dimensional and technical parameters of the PV panel were chosen based on the optimal mounting conditions for the roof building structure, with a total area of S_{house}=85 m², with a side facing the roof facing south $S_{roof.south\ side}$=64,8 m².

The simulation is performed in the 24-hour time zone. The solar insolation data is taken from NASA's open access site.

Significant factors that directly affect the change of the output PV module characteristics are the operating temperature and the values of solar insolation.

On Fig. 5 shows the graphs of the initial parameters and gives their main characteristics on the test day (July 2018). Shading and network losses are not counted.

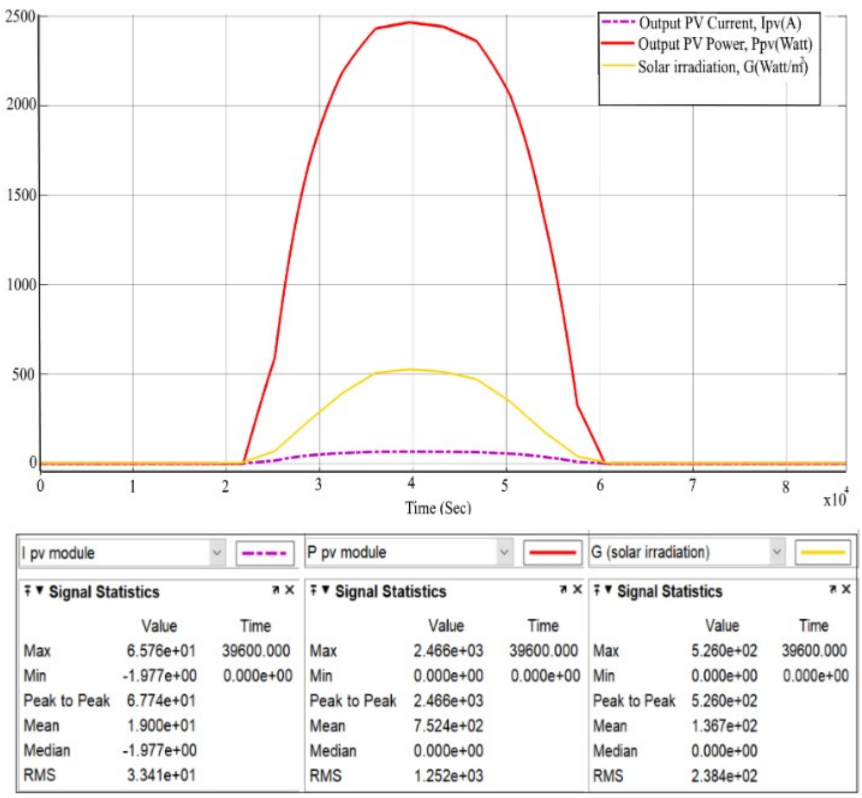


Figure 5 - PV module output data parameters

Conclusions. The preconditions for the construction and operation of Energy Smart Community systems are described. The optimizing task is the use of electricity from the power grid is determined. Communications with other smart power supply systems are described. The efficiency analysis PV modules with the help of a software module in the Matlab Simulink system is carried out. The generation independence of electric power depending on the solar insolation level influence and cross-emitting home dimming are determined.

The consumer functioning basic modes as the future key elements of a reasonable energy environment are determined. The Energy Smart Community adaptation algorithm systems at the technical and economic levels are presented. The calculations and studies made available to assess the introducing feasibility PV systems for a private household and point to their further prospect of use as additional software for conducting studies related to PV systems.

Acknowledgement

This work is part of PhD research in the frame of «Norwegian-Ukrainian cooperation on research-based education in innovative sustainable and energy efficient systems Eurasia CPEA-LT-2016/10044 Project».

References

1. S. Denysiuk, " Guidelines of technological concepts of Smart Grid in power system," Power engineering: economics, technique, ecology, vol. 1 (31), pp. 7–20, 2014.
2. A. Kirilenko and S. Denysiuk, " Modern tendencies of construction and management modes of Electroenergy networks" Energy saving. Power engineering. Energy audit, vol. 9, special. vol. T2: Power electronics and energy efficiency, pp. 82–94, 2014.
3. S. Denysiuk and D. Derevianko " A novel method of complex reliability assessment in microgrids withdistributed generation", presented at International Conference on Modern Electrical and Energy Systems (MEES), Kremenchuk, Ukraine, pp. 212–215, 2017,
4. Resolution "On the establishment of green" tariffs for electric energy for private households" Available: https://zakon.rada.gov.ua/laws/show/z1022-16.Accessed on: 20.10.2018.
5. "Draft Law on Amendments to certain Laws of Ukraine on Ensuring Competitive Conditions for the Production of Electricity from Alternative Energy Sources " Available: https://iportal.rada.gov.ua.Accessed on: 22.10.2018.
6. National Energy and Utilities Regulatory Commission: " On the status of the renewable energy sector in the first quarter of 2019" Available: http://www.nerc.gov.ua. Accessed on: 02.04.2019.
7. E. Omine, H. Hatta and T. Ueno, "A study of economic feasibility of Smart Community. - calculation of profit of Community Operator considering introduction of battery and co-generation systems," 2016 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT), Minneapolis, MN, pp. 1–5, 2016,
8. A. Ożadowicz "A New Concept of Active Demand Side Management for Energy Efficient Prosumer", Microgrids with Smart Building Technologies. Energies., vol. 10(11), p. 1771, 2017.
9. NYSEG: About the Energy Smart Community - Tompkins county, Available: https://www.nysegsmartsolutions.com, Accessed on: 20.03.2019.
10. "Smart Community Aruba", Available: http://www.smartcommunityaruba.aw/about, Accessed on: 20.03.2019.
11. S. Bracco et al., "An Optimization Model for Polygeneration Microgrids with Renewables, Electrical and Thermal Storage: Application to the Savona Campus," IEEE International Conference on Environment and Electrical Engineering and IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Palermo, Italy, 2018, pp. 1-6
12. E. Espe, V. Potdar and E. Chang, "Prosumer Communities and Relationships in Smart Grids: A Literature Review", Evolution and Future Directions. Energies, vol. 11. 2018.
13. R.Verschae, T. Kato and T. Matsuyama, "Energy management in prosumer communities: A coordinated approach". Energies, vol. 9, p.562, 2016.
14. S. E. Collier, "The emerging enernet: Convergence of the smart grid with the internet of things". IEEE Ind. Appl. Mag., vol. 23, pp.12–16. 2017.
15. Z. Liu, Q. Wu, S. Huang and H. Zhao, "Transactive energy: A review of state of the art and implementation". In Proceedings of the 2017 IEEE Manchester PowerTech, Manshester, UK, pp. 1–6, 18–22 June 2017.
16. A. Richter, I. Hauer, M. Wolter, "Algorithms for Technical Integration of Virtual Power Plants into German System Operation", Advances in Science, Technology and Engineering Systems Journal, vol. 3, No. 1, 135–147, 2018.
17. W.-P. Schill1, A. Zerrahn and F. Kunz, "Prosumage of solar electricity: pros, cons, and the system perspective", DIW Berlin, German Institute for Economic Research, p. 36, 2017.

18. Y. Wu, J. J. Gao and L. R. Yu, "Demand chain management — The new source of profit increase," presented at 2009 16th International Conference on Industrial Engineering and Engineering Management, Beijing, pp. 1483–1487, 2009.
19. G. Da Silva, P. Ilic, and S. Karnouskos, "The Impact of Smart Grid Prosumer Grouping on Forecasting Accuracy and Its Benefits for Local Electricity Market Trading. " IEEE Transactions on Smart Grid, vol. 5(1), pp 402–410, 2014.
20. A. Keshtkar, S. Arzanpour and F. Keshtkar, "Adaptive residential demand-side management using rule-based techniques in Smart Grid environments". Energy Build, vol.133, pp. 281–294, 2016.
21. S. Parvathy, N.R. Patne and A.M. Jadhav, "A smart demand side management mechanism for domestic energy consumers with major HVAC load". In Proceedings of the 2016 International Conference on Electrical Power and Energy Systems (ICEPES), Bhopal, India, pp. 504–511, 14–16 December 2016.
22. S. Denysiuk, R. Strzelecki and V. Opryshko, "The smart grid concept implementation by expanding the use of demand side managment and modern power electronic installations" Power engineering: economics, technique, ecology, vol. 4 (46), pp. 7–17, 2016
23. A. Amato, B. Di Martino, and S. Venticinque, "Semantically augmented exploitation of pervasive environments by intelligent agents, " in ISPA. IEEE, pp. 807–814, 2012.
24. H. Lu, K. Huang, M. Azimi, Guo L. Blockchain technology in the oil and gas industry: A review of applications, opportunities, challenges, and risks IEEE Access, vol.7, 2019
25. A. Ozadowicz and J. Grela, "An event-driven building energy management system enabling active demand side management" In Proceedings of the 2016 Second International Conference on Event-based Control, Communication, and Signal Processing (EBCCSP), Krakow, Poland, pp. 1–8, 13–15 June 2016.
26. M. Rasheed, N. Javaid, M. Awais, Z. Khan, U. Qasim, N. Alrajeh, Z. Iqbal and Q. Javaid, Real time information-based energy management using customer preferences and dynamic pricing in smart homes". Energies, vol. 9, p. 542, 2016.
27. Lilis, G.; Conus, G.; Asadi, N.; Kayal, M. Towards the next generation of intelligent building: An assessment study of current automation and future IoT based systems with a proposal for transitional design. Sustain. Cities Soc. 2017, 28, 473–481.

УДК 621.31

П.В. Соколовський., PhD студент **ORCID** 0000-0002-0113-4479
Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського»
Р. Шарма., PhD, доц. **ORCID** 0000-0003-4260-1130
Університет Південно-Східної Норвегії, Порсгрунн (Porsgrunn)

ОЦІНКА ЕФЕКТИВНОСТІ РОБОТИ PV СИСТЕМ ЗАБЕЗПЕЧЕННЯ ЕЛЕКТРОЕНЕРГІЄЮ В УМОВАХ ЩІЛЬНОЇ МІСЬКОЇ ЗАБУДОВИ

В роботі описані передумови для планування та побудови розумного співтовариства Energy Smart Community. Охарактеризовано стан розвитку сектора ВДЕ, а саме PV станцій в енергетичній структурі Об'єднаної енергетичної системи України. Особливості побудови архітектури Energy Smart Community передбачає аналіз можливостей приєднання власних генеруючих потужностей в якості енергетичної складової цієї системи. Описані енергетичні та економічні критерії такого приєднання. Проаналізовано наведено іноземний досвід побудови та впровадження Energy Smart Community в енергетичні системи на основі пілотних проектів NYSEG та SCA для подальшого його наукового дослідження та випробування. Звикористанням програмного модуля в середовищі Matlab Simulink побудовано та описано роботу на прикладі довільного PV модуля з виділенням його основних залежностей від узагальненого показника сонячної інсоляції. Отримані дані вказують на всі передумови можливості широкої участі приватних PV систем забезпечення електроенергією в якості основного активу функціонування Energy Smart Community

Ключові слова: Energy Smart Community (ESC), Smart City, Smart Grid, Demind – Side Management (DSM), Energy Storage Systems (ESS), photovoltaic (PV), Virtual Power Plant (VPP), renewable energy sources (RES), prosumage, Solar Power Plant (SPP), distributed energy resources (DERs), Energy Storage System (ESS).

Надійшла 18.02.2019
Received 18.02.2019