Lecture Notes in Electrical Engineering 1446

Ľubomír Beňa
Zsolt Čonka
Damian Mazur
Ján Zbojovský *Editors*

Research and Developments in Electrical Power Engineering

Proceedings of the 12th International Scientific Symposium on Electrical Power Engineering, Elektroenergetika 2024, September 11–13, 2024, Stará Lesná, Slovakia

Springer

Lecture Notes in Electrical Engineering 1446

Series Editors

Leopoldo Angrisani, *Department of Electrical and Information Technologies Engineering, University of Napoli Federico II, Napoli, Italy*
Marco Arteaga, *Departament de Control y Robótica, Universidad Nacional Autónoma de México, Coyoacán, Mexico*
Samarjit Chakraborty, *Fakultät für Elektrotechnik und Informationstechnik, TU München, Munich, Germany*
Shanben Chen, *School of Materials Science and Engineering, Shanghai Jiao Tong University, Shanghai, China*
Tan Kay Chen, *Department of Electrical and Computer Engineering, National University of Singapore, Singapore, Singapore*
Rüdiger Dillmann, *University of Karlsruhe (TH) IAIM, Karlsruhe, Germany*
Haibin Duan, *Beijing University of Aeronautics and Astronautics, Beijing, China*
Gianluigi Ferrari, *Dipartimento di Ingegneria dell'Informazione, Sede Scientifica Università degli Studi di Parma, Parma, Italy*
Manuel Ferre, *Centre for Automation and Robotics CAR (UPM-CSIC), Universidad Politécnica de Madrid, Madrid, Spain*
Faryar Jabbari, *Department of Mechanical and Aerospace Engineering, University of California, Irvine, USA*
Limin Jia, *State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing, China*
Janusz Kacprzyk, *Intelligent Systems Laboratory, Systems Research Institute, Polish Academy of Sciences, Warsaw, Poland*
Alaa Khamis, *Department of Mechatronics Engineering, German University in Egypt El Tagamoa El Khames, New Cairo City, Egypt*
Torsten Kroeger, *Intrinsic Innovation, Mountain View, USA*
Yong Li, *College of Electrical and Information Engineering, Hunan University, Changsha, China*
Qilian Liang, *Department of Electrical Engineering, University of Texas at Arlington, Arlington, USA*
Ferran Martín, *Departament d'Enginyeria Electrònica, Universitat Autònoma de Barcelona, Bellaterra, Spain*
Tan Cher Ming, *College of Engineering, Nanyang Technological University, Singapore, Singapore*
Wolfgang Minker, *Institute of Information Technology, University of Ulm, Ulm, Germany*
Pradeep Misra, *Department of Electrical Engineering, Wright State University, Dayton, USA*
Subhas Mukhopadhyay, *School of Engineering, Macquarie University, Sydney, NSW, Australia*
Cun-Zheng Ning, *Department of Electrical Engineering, Arizona State University, Tempe, AZ, USA*
Toyoaki Nishida, *Department of Intelligence Science and Technology, Kyoto University, Kyoto, Japan*
Luca Oneto, *Department of Informatics, Bioengineering, Robotics and Systems Engineering, University of Genova, Genova, Italy*
Bijaya Ketan Panigrahi, *Department of Electrical Engineering, Indian Institute of Technology Delhi, New Delhi, India*
Federica Pascucci, *Department di Ingegneria, Università degli Studi Roma Tre, Rome, Italy*
Yong Qin, *State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing, China*
Gan Woon Seng, *School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore, Singapore*
Joachim Speidel, *Institute of Telecommunications, University of Stuttgart, Stuttgart, Germany*
Germano Veiga, *FEUP Campus, INESC Porto, Porto, Portugal*
Haitao Wu, *Academy of Opto-electronics, Chinese Academy of Sciences, Beijing, China*
Walter Zamboni, *Department of Computer Engineering, Electrical Engineering and Applied Mathematics, DIEM—Università degli studi di Salerno, Fisciano, Italy*
Kay Chen Tan, *Department of Computing, Hong Kong Polytechnic University, Hong Kong, Hong Kong*

The book series *Lecture Notes in Electrical Engineering* (LNEE) publishes the latest developments in Electrical Engineering—quickly, informally and in high quality. While original research reported in proceedings and monographs has traditionally formed the core of LNEE, we also encourage authors to submit books devoted to supporting student education and professional training in the various fields and applications areas of electrical engineering. The series cover classical and emerging topics concerning:

- Communication Engineering, Information Theory and Networks
- Electronics Engineering and Microelectronics
- Signal, Image and Speech Processing
- Wireless and Mobile Communication
- Circuits and Systems
- Energy Systems, Power Electronics and Electrical Machines
- Electro-optical Engineering
- Instrumentation Engineering
- Avionics Engineering
- Control Systems
- Internet-of-Things and Cybersecurity
- Biomedical Devices, MEMS and NEMS

For general information about this book series, comments or suggestions, please contact leontina.dicecco@springer.com.

To submit a proposal or request further information, please contact the Publishing Editor in your country:

China

Jasmine Dou, Editor (jasmine.dou@springer.com)

India, Japan, Rest of Asia

Swati Meherishi, Editorial Director (Swati.Meherishi@springer.com)

Southeast Asia, Australia, New Zealand

Ramesh Nath Premnath, Editor (ramesh.premnath@springernature.com)

USA, Canada

Michael Luby, Senior Editor (michael.luby@springer.com)

All other Countries

Leontina Di Cecco, Senior Editor (leontina.dicecco@springer.com)

**** This series is indexed by EI Compendex and Scopus databases. ****

Ľubomír Beňa · Zsolt Čonka · Damian Mazur · Ján Zbojovský
Editors

Research and Developments in Electrical Power Engineering

Proceedings of the 12th International Scientific Symposium on Electrical Power Engineering, Elektroenergetika 2024, September 11–13, 2024, Stará Lesná, Slovakia

Springer

Editors
Ľubomír Beňa
Technical University of Košice
Košice, Slovakia

Zsolt Čonka
Technical University of Košice
Košice, Slovakia

Damian Mazur
Rzeszów University of Technology
Rzeszów, Poland

Ján Zbojovský
Technical University of Košice
Košice, Slovakia

ISSN 1876-1100 ISSN 1876-1119 (electronic)
Lecture Notes in Electrical Engineering
ISBN 978-3-031-97332-1 ISBN 978-3-031-97333-8 (eBook)
https://doi.org/10.1007/978-3-031-97333-8

© The Editor(s) (if applicable) and The Author(s), under exclusive license
to Springer Nature Switzerland AG 2025

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

If disposing of this product, please recycle the paper.

Preface

This volume of Lecture Notes in Electrical Engineering gathers selected papers presented at the 12th International Scientific Symposium on Electrical Power Engineering, Elektroenergetika 2024, September 11–13, 2024, Stará Lesná, Slovakia. The conference was organized by the Department of Electrical Power Engineering, Faculty of Electrical Engineering and Informatics, Technical University of Košice. The Symposium Elektroenergetika 2024 provides a unique interdisciplinary forum for discussion about the current electrical power engineering and industrial applications and opens visions for the energy supplies of the future. It is intended for managers, scientists, engineers, designers, and planners from industry, government, and academia who have an interest in sustainable electricity for the today and future.

The presented papers cover a wide range of topics:

- Generation of Electricity, Transmission, Distribution and Consumption of Electricity,
- High Voltage Technique and Diagnostics in Power Engineering,
- Power Systems Relaying, Faults Analysis,
- Power System Control, Liberalisation of Electricity Market,
- Smart Grids,
- Electromobility,
- Data Security in Power Engineering, Deep Learning and Artificial Intelligence.

The organizers received 54 contributions from 8 countries around the world. After a thorough peer-review process (double-blind review), the committee accepted 40 papers for conference proceedings prepared by 142 authors from 7 countries (acceptance rate 74%). At least two independent reviewers reviewed each paper. Reviewers needed to evaluate each paper by answering, among others, the questions about the originality of the paper, the significance of presented results, comprehensibility, and presentation of chapters and relevance for this conference. The reviewers came from 7 countries in Europe. Each article was checked using iThenticate and achieved a similarity index of less than 25%.

We would like to thank the members of the International Scientific Committee for their hard work during the review process. We acknowledge all people who contributed to the staging of Elektroenergetika 2024: authors, committees, and sponsors. Their involvement and hard work were crucial to the success of the conference.

May 2025

Ľubomír Beňa
Zsolt Čonka
Damian Mazur
Ján Zbojovský

Organization

Symposium Guarantee

Roman Cimbala	Technical University of Košice, SK

Steering Committee

Juraj Kurimský	Technical University of Košice, SK
Marek Pavlík	Technical University of Košice, SK
Ľubomír Beňa	Technical University of Košice, SK
Jaroslav Džmura	Technical University of Košice, SK
Dušan Medveď	Technical University of Košice, SK
Jana Varnavčinová	Technical University of Košice, SK
Jaroslav Petráš	Technical University of Košice, SK
Róbert Štefko	Technical University of Košice, SK
Ján Zbojovský	Technical University of Košice, SK
Anikó Szakál	Special Issue Editor, APH Executive Editor, Óbuda University, HU
Zsolt Čonka (Special Issue APH Guest Editor)	Technical University of Košice, SK

Scientific Committee

József Domokos	Sapientia University, RO
György Molnár	Óbuda University, HU
Antin Beláň	STU Bratislava, SK
Július Bems	ČVUT Praha, CZ
Ľubomír Beňa	Technical University of Košice, SK
Judith Pálfi	Óbuda University, HU
Kristina Berzina	Riga Technical University, LV
Peter Birkner	Bergischen Universität Wuppertal, DE
Peter Braciník	Žilinská univerzita, SK
Ivo Doležel	AV ER Praha, CZ
László Szamel	Budapest University of Technology and Economics, HU
Illia Diahovchenko	Sumy State University, UA

Jiří Drápela	VUT Brno, CZ
Emil Dvorský	ZČU Plzeň, CZ
Anna Gawlak	Czestochowa University of Technology, PL
Dionýz Gašparovský	STU Bratislava, SK
Zsolt Temesvári	Óbuda University, HU
Mircea Buzdugan	Technical University of Cluj Napoca, RO
Radomír Goňo	VŠB TU Ostrava, CZ
Rainer Haller	Regensburg, DE
Zdeněk Hradílek	VŠB – TU Ostrava, CZ
František Janíček	STU Bratislava, SK
Péter Kádár	Óbuda University, Budapest, HU
Rumen Kirov	TU Varna, BG
Jaroslav Knápek	ČVUT Praha, CZ
Michal Kolcun	Technical University of Košice, SK
Sebastian Kot	Czestochowa University of Technology, PL
Tomáš Králik	ČVUT Praha, CZ
Dušan Krokavec	Technical University of Košice, SK
Juraj Kurimský	Technical University of Košice, SK
Jaroslav Lelák	STU Bratislava, SK
Tatiana Lomane	TU Riga, LV
Anatolij Mahnitko	TU Riga, LV
J. Rudas Imre	Óbuda University, HU
Zbyněk Martinek	ZČU Plzeň, CZ
Karel Máslo	ČEPS, CZ
Marián Mešter	Východoslovenská distribučná, a.s., SK
György Morva	University of Budapest, HU
Zdeněk Müller	ČVUT Praha, CZ
Michael Negnevitsky	University of Tasmania, AU
Karel Nohač	ZČU Plzeň, CZ
Irina Oleinikova	Norwegian University of Science and Technology, NO
Alena Otčenášová	Žilinská univerzita, SK
Daniela Perduková	Technical University of Košice, SK
Ervin Rácz	Óbuda University, HU
Marek Roch	Žilinská univerzita, SK
Stanislav Rusek	VŠB – TU Ostrava, CZ
Levente Kovács	Óbuda University, HU
Antanas Sauhatas	TU Riga, LV
Rasid Sitdikov	TSTU Tashkent, UZB
Josef Tlustý	ČVUT Praha, CZ
Petr Toman	VUT Brno, CZ
Toomas Vaimann	TU Tallin, EE

Ferenc Novothny	Óbuda University, HU
Damian Mazur	Rzeszów University of Technology, PL
Jozef Kúdelčík	Žilinská univerzita, SK
Diana Zalostiba	Riga Technical University, LV
Inga Zicmane	Riga Technical University, LV
Bohuslav Kwiatkowski	Rzeszów University of Technology, PL
Paweł Pijarski	Lublin University of Technology, PL
Henryk Wachta	Rzeszów University of Technology, PL
Tomasz Binkowski	Rzeszów University of Technology, PL

Contents

Eliminating Overloads of Power Lines Using Redispatching of Source Power 1
Paweł Pijarski, Adrian Belowski, and Ľubomír Beňa

Analysis of Residential Charging Station Occupancy Models 14
Matej Tkac, Martina Kajanova, and Peter Braciník

Use of a Dynamic Model for Solving Switching in Transmission Networks 24
Ján Hevessy, Karel Máslo, Radim Chrapek, and Rastislav Šmidovič

Assessment of Low-Temperature Waste Heat Utilization in District Heating Sector 33
Adam Kubín, Jiří Vašíček, Michaela Valentová, and Jiří Vecka

Analyzing the Impact of Photovoltaic Generation and Electric Vehicle Penetration on Distribution Network Power Quality 48
Illia Diahovchenko, Andrew Keane, Mykhailo Petrovskyi, Ihor Lebedynskyi, and Roman Petrichenko

Semiconductor Selection for High-Efficiency PSFB Converter 61
Daniel Gordan, Marek Pastor, Tomáš Basarik, and Tadeáš Kmecik

WLS State Estimation in MV Distribution Network Feeder with RTU Installation 72
Vit Krcal and David Topolánek

Collecting More Information About the LV Distribution Grid and Customers 84
Peter Holcsik, István Kormos, and Péter Kádár

Conventional and AI Control Methods Dual-Active-Bridge DC/DC Converter 97
Tadeáš Kmecik, Tomáš Basarik, Daniel Gordan, Peter Girovský, and Milan Lacko

Evaluation of the Methods for Detecting Island Operation Within External Devices 108
Viktor Jurák, David Topolánek, and Jaroslava Orságová

A Short Review of Selected Power Consumption Forecasting Techniques: Application in Artificial Intelligence Models 120
Martin Matejko, Peter Braciník, Marek Roch, and Marián Tomášov

Start from Dark Test for the Bohunice V2 Nuclear Power Plant 129
Stanislav Prieložný, Martin Jedinák, Jozef Valiček, Peter Gamboš, Anton Beláň, Felix Skoršepa, and Vladimír Šulko

Characterization of Corona Discharge-Induced Electromagnetic Interference 142
Bystrík Dolník and Dávid Dzúr

PPA Market in the Czech Republic in the Context of the EU Electricity Market Design Reform 151
Martin Tichý, Július Bemš, and Rostislav Krejcar

Shifting Paradigms: Energy Flexibility in the Age of Renewables 159
Daniel Běhal and Július Bemš

Reliability of Power Supply in EG.D 168
Martin Kašpírek and Daniel Kouba

Using WAMS to Determine the System Inertia - Verification on a Dynamic Model 181
Zsolt Čonka and Karel Máslo

Comparative Evaluation of Open-Source Tools for Infrastructure Reliability Analysis 189
Matej Vrtal, Michal Beloch, Pavel Praks, Radek Fujdiak, Jan Benedikt, and Petr Toman

Computation Time Optimization Strategies for Critical Infrastructure Simulator 202
Matej Vrtal, Jan Benedikt, Radek Fujdiak, Pavel Praks, and Petr Toman

The Potential Savings in Power Consumption of Greenhouse Lighting Caused by the Transition from High-Pressure Sodium Lamps to White LED 212
Lukas Vavra, Tomas Novak, Pavel Valicek, and Radomir Gono

Towards Deeper Understanding of Public EV Charging Load Patterns: Case Study Covering Data from Prague, Czechia 222
Marek Miltner, Artem Bryksa, Ondřej Štogl, Daniel Vašata, Magda Friedjungová, and Oldřich Starý

Voltage Management in the Public Distribution Grid with a Comprehensive FLT Model 234
Marek Bobček, Judith Pálfi, Róbert Štefko, Zsolt Čonka, and Marek Miltner

Dependence of Reactive Power Magnitude Variations on Power Supply Voltage Distortion 243
Pavel Stanko, Michal Regula, and Alena Otcenasova

Cellular HV Insulation Surface Resistance Monitor for Substations: The Principle and Design 257
Jakub Gača, Juraj Kurimský, and Roman Cimbala

Reinforcement Learning in Electrical Installations 266
Jaroslav Petráš and Ardian Hyseni

Development and Direction of Microgrids: Pathway to Tomorrow's New Horizons 278
Róbert Štefko, Marek Bobček, František Margita, and Wiesława Malska

Research on the Energy Efficiency of Road Lighting in Mountainous Terrain ... 291
Marcin Leśko, Krzysztof Baran, Jozef Király, and Ľubomír Beňa

The Impact of Specified Operating and Investment Factors on the Profitability of Road Lighting Modernization 304
Henryk Wachta, Tomasz Binkowski, Krzysztof Baran, Róbert Štefko, and Ľubomír Beňa

Road Lighting Control Systems and Their Validity on the Example of Selected Municipalities 316
Krzysztof Baran, Marcin Leśko, Samuel Bucko, and Ľubomír Beňa

Passive Filtering in an Inverter Drive System 327
Marek Nowak, Tomasz Binkowski, Ľubomír Beňa, and Zsolt Čonka

Technology of Custom Designed Mono-Si Photovoltaic Cells for Specific Purposes and Energy Communities 342
Milan Belik

Photovoltaic System Designing for Power Supply of School in Ukrainian Conditions 353
Olena Rubanenko

Evaluation of the Shielding Effectiveness of a Nanofluid-Additive Carbon Coating 364
Ján Zbojovský, Roman Cimbala, Ardian Hyseni, and Tomasz Binkowski

Big Data in Electric Power Engineering 375
Ardian Hyseni and Jaroslav Petráš

Dielectric Properties of Nanofluids Based on Transformer Oil from the Perspective of Dielectric Relaxation SpeCctroscopy and Temperature Dependencies 383
Jozef Király, Samuel Bucko, Roman Cimbala, and Mateusz Suliga

Time Domain Spectroscopy of Ferrofluid Based on GTL Oil 391
Samuel Bucko, Peter Havran, Jozef Király, and Jarosław Wiśniowski

Dielectric Properties of Magnetic Fluids Under Thermal Aging 399
Roman Cimbala and Gregor Tomko

An Overview of PV Power Forecasting Methods 413
David Kecek, Daniel Běhal, and Július Bemš

Modeling Scenarios of the Impact of Renewable Energy Generation Volumes on the Capacity Balance in the Baltic States 423
Anatolijs Mahnitko, Tatjana Lomane, Inga Zicmane, Timurs Kuzņecovs, and Michael Negnevitsky

Influences on Energy Generation in Photovoltaic Systems 438
Barz Cristian, Erdei Zoltan, Chiver Olivian, and Syrek Przemyslaw

Author Index 449

Photovoltaic System Designing for Power Supply of School in Ukrainian Conditions

Olena Rubanenko[1,2,3](✉)

[1] RICE, University of West Bohemia, Pilsen, Czech Republic
olenarubanenko@ukr.net
[2] Department of ESS, Vinnitsya National Technical University, Vinnytsia, Ukraine
[3] Department of Wind Energy, Institute of Renewable Energy, Kyiv, Ukraine

Abstract. Photovoltaic system in Ukraine is viewed not only as a business opportunity, but also as a way to diversify energy supply and a component of energy safety. Stability and efficiency of Ukraine's energy sector primarily in the development of distributed generation, including green energy. Case-study projects of designed PV-system are presented in paper. Digital Twins of different type of PV-systems designing with usage relevant software is shown.

Keyword: Renewable Energy · Photovoltaic System · Digital Twin

1 Introduction

As a result of another massive attack by the Russian military on the energy infrastructure [1], Ukraine sharply reduced electricity exports and increased imports. According to Energy Map, during the week of May 6–12, Ukraine increased electricity imports by 51% to 73.2 thousand MWh due to the fifth massive drone strike on the Ukrainian energy sector this year. After the attack, imports were carried out not only during peak consumption hours, but also throughout the day from all available directions.

The weekly breakdown by country is as follows: 53% (39 thousand MWh) came from Hungary; 17% (12.6 thousand MWh) – from Slovakia; 13% (9.4 thousand MWh) – from Moldova; 12% (8.3 thousand MWh) – from Romania; 5% (3.9 thousand MWh) – from Poland [2]. Nowadays, photovoltaic systems in Ukraine provide about 75% of renewable energy production [3]. Attacks, problems with the logistical support of equipment and qualified personnel affect the development segments of this sector and the choice of regions for safe new installed capacity. The problem with the interruption of the power supply strongly affects the chosen type of photovoltaic system and the efficiency of their operation.

2 Benefits of Distributed Power Sources

Decentralization in the Energy sector is the maximum support and construction of small, geographically dispersed sources of power generation that are as close as possible to consumers. Main benefit of distributed power sources is the possibility of functioning

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2025
Ľ. Beňa et al. (Eds.): ELEKTROENERGETIKA 2024, LNEE 1446, pp. 353–363, 2025.
https://doi.org/10.1007/978-3-031-97333-8_32

autonomously. It is useful in current conditions from the technological point of view and from the management point of view [4]. Systematization of main benefits of distributed power sources are presented in Fig. 1.

Energy services are essential for basic human protection and dignity in times of war, two of the main ethical goals of humanitarian assistance. However, millions of displaced people lack access to clean and safe energy services, in part because funding for such services is inadequate.

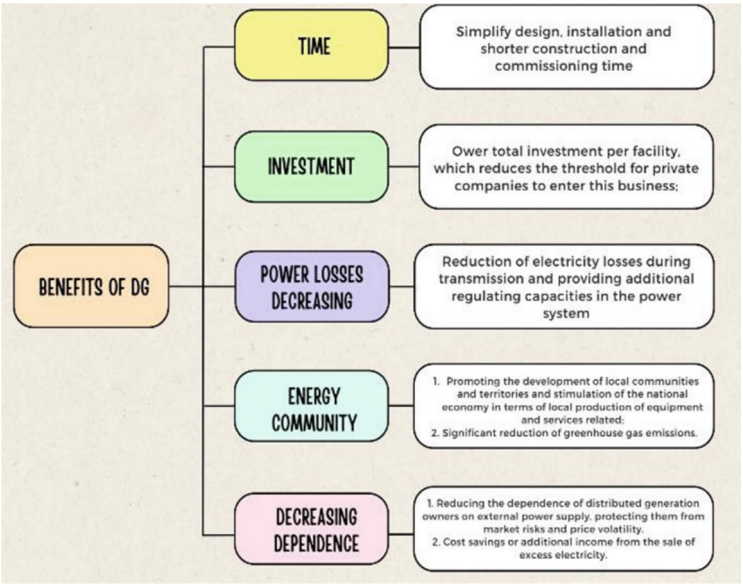


Fig. 1. Classification of DG benefits for Ukraine

3 Appliency Condition of Renewable Energy Sources

The transition of the humanitarian sector to a "sustainable energy" model includes opportunities to develop better energy solutions and services. However, a lack of skills among implementing agencies and a tendency to take a short-term view among donors and host communities has led to a "buy and deliver" model that primarily distributes energy equipment to IDPs (internally displaced person), focusing on quantity rather than quality. At the same time, raising the level of knowledge in the field of green energy and mastering practical tools for designing sustainable energy solutions can provide an impetus for their practical implementation in providing IDPs with housing using green technologies.

Green energy for shelters and temporary settlements of IDPs can help solve the problems with the settlement of people and ensure their energy independence [5].

In June 2023, the Law on "green" transformation of the energy system developed. It provides for the introduction of a register of guarantees of the origin of electric energy

produced from renewable energy sources, the introduction of a system of net metering net billing, increasing the flexibility of the auction model of supporting electricity production from renewable energy sources and progressive innovations, including energy cooperative [6] and can be presented on flow-chart of the Fig. 2.

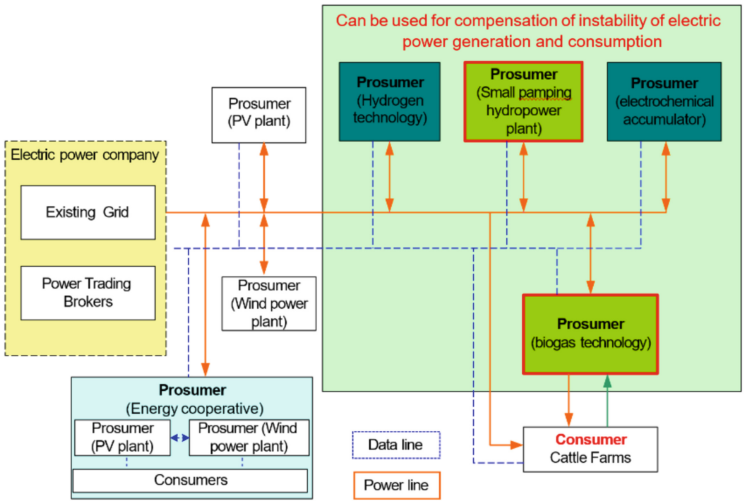


Fig. 2. Prosumers model

In war conditions, householder photovoltaic systems are starting be more benefit for saving energy security. If don't consider external issues, photovoltaic generation is gradually developing, in particular thanks to the segment of medium and small photovoltaic systems. Still the deficit of energy storage systems is one of the key obstacles in further development. It is difficult to estimate the number and capacity of such systems, but their importance for the stability of energy supply is great. The number of prosumers – farms and enterprises that produce their own energy – is growing. This makes it possible to reduce dependence on external supply and promotes sustainable development. However, owners now need to be motivated to add energy storage systems and improve their photovoltaic power system to maximize their potential to support the energy system.

Another important area for the widespread use of photovoltaic generation is to ensure the uninterrupted operation of socially important facilities. Critical and social infrastructure facilities, such as water supply systems, food storage and production facilities, important transportation hubs, telecommunication networks, and medical facilities, schools, universities, and kindergartens. Additional energy sources are needed to ensure their reliability. Grant funding can help reduce the vulnerability of these facilities by stimulating the adoption of new technologies and increasing energy resilience [3]. In the reason of the insufficient number of generating capacities in the energy system of Ukraine due to damage to energy facilities by enemy attacks NEC "Ukrenergo" proved consumption limits or divided grid for energy local system ("energy island"). This means that should be used schedules of hourly electricity shutdowns to maintain the balance between consumption and generation in the energy system of Ukraine.

Power balance for energy local system is eq. (1):

$$P_{CS}(t) + \sum_{i=1}^{n} P_i(t) - \sum_{j=1}^{m} P_{TSj}(t) - \Delta P(t) \pm P_{stor.}(t) = 0 \quad (1)$$

where t is current time, *Pcs(t)* is power feed to the energy local system from distributed power grid; *Pi (t)* is power generation of RES, which installed in energy local system; *PTSj(t)* is power of substation (customers load); n is the number of renewable energy technology in the energy local system; m is number of consumers; *Pstor.(t)* is power, which possible accumulate in proficit time from energy communities RES and usage in deficit time, $\Delta P(t)$ is power losses, which is occurred during transmit power flow in the electrical networks. Decreasing of value $\Delta P(t)$ is one of the optimization task and push to choose power sources more closed for consumers, but with tale into account level voltage transmission line. In (1) is an important note, that power generation elements are power from grid (first element); power from RES (second element) and power from storage system (fifth element) and used for power supply energy local system. Optimization of members local energy system consumption is way to reach power balance. Decentralization of energy sources and creating energy islands deals with technical problems, for example sectionalization [6].

Increasing energy efficiency RES can be caught by the way mixed different technology, depend on meteorological characteristics location. Power of RES is presented:

$$\sum_{i=1}^{n} P_i(t) = \sum_{l=1}^{w} P_l(t) + \sum_{k=1}^{q} P_k(t) + \sum_{z=1}^{s} P_z(t) \quad (2)$$

w is the number of RESs in the energy cooperative that depend on meteorological conditions; $P_l(t)$ is capacity of renewable energy sources that depend on meteorological conditions; q is the number of controlled RESs in the PS; $P_k(t)$ is power of controlled RESs; z is the number of controlled RESs in the energy cooperative; $P_z(t)$ is power of partially controlled RES in in the energy cooperative. Prediction of power generation wind and photovoltaic power station still can be improved. Wind power plants and photovoltaic power plants can have uneven generation schedules, depending on meteorological factors. Under controlled RES will understand hydrogen technologies and biogas plants. Under partially controlled RES we will understand small, mini, and micro-hydro. A promising approach in terms of supporting decarbonization policy is to reduce imbalances in the PS, which is to compensate for the uneven generation schedules of wind power plants (WPPs) and photovoltaic power plants (PVPs), by using other RES, such as biogas technologies and hydrogen plants. Also, reducing the non-uniformity of the RESs generation schedule will significantly increase their energy efficiency in the electricity balance of energy systems [7].

In the proposed paper is the design of a photovoltaic system for a typical University property in location middle Europe. Digital Twin PV system allows image and simulate operational mode, choice optimal parameters and create great visual for investors. For design of PV system was used PV*SOL Premium software 2024.

In paper was shown few typical models of PV system, which can be installed. It is possible design in PV*SOL Premium grid-connected PV system; grid-connected PV system with electrical appliances; grid-connected PV system with electrical appliances

and battery systems; grid-connected PV system with electrical appliances and electrical vehicles; grid-connected PV system with electrical appliances and electrical vehicles and battery systems; grid-connected PV system with electrical appliances and thermal systems; stand-alone PV system; stand-alone PV system with Backup Generator. 3D-model typical school with roof PV-system presented on Fig. 3. All trees were created in real size for assessment sheading influence. It is a simple model of PV system, and doesn't show obstacle on the roof (chimney, windows, and distance between rows of PV panels). In the first view studied building has not obstacles on the roof. Proposed project is an emergency solution for particulary power supply school. The first and more easy realized project is grid-connected PV system. A lot of foreign donors proposed used or new PV modules, inverters of for hospitals and schools for free. In this case better used all roof square. The PV system consists of 4 parts. 3D view for different types of PV system models wasn't changed.



Fig. 3. 3D model of PV system

Design of first PV-system roof area is presented in the Fig. 4.

The flow-chart of presented system is very simple, and can be shown in Fig. 5, because all electricity, which is produced will be send to the grid. It is possible in summertime, when school has holidays. This variant is not energy efficiency, because all produced energy is sent to power grid, but can be used for decided particular task for cover energy deficit in power grid in large city, where there exist problem with free space for installation PV system.

Other case study PV system include appliances. PV*Sol Premium software optimizes configuration of inverters and proposed few variants. In the proposed project was chosen inverter configuration:

- 1st area Fig. 4 (a) and Fig. 4 (c) use 12 units PLENTICORE M G3 12.5 (battery option) Kostal with sizing factor 116.5% in configuration MPP 1: 1 × 14; MPP 2: 1 × 14 for south configuration; MPP 1: 1 × 14; MPP 2: 1 × 14 for north orientation.
- 2nd area Fig. 4 (b) and Fig. 4 (d) use 2 units PIKO 17 (v3) Kostal with sizing factor 110.1% in configuration MPP 1: 1 × 12; MPP 2: 1 × 12; MPP 3: 1 × 12 for east

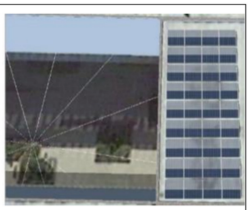
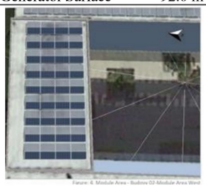
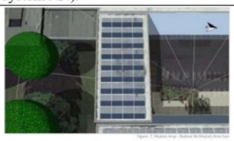
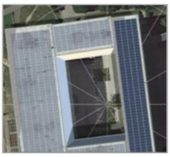
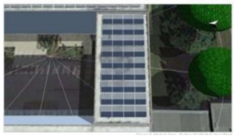
	
(a)	(b)
First part of the roof PV system 168 units x LR5-72 HBD 520 M (v3) LONGI Solar; Inclination 10 ° Orientation South 263° Installation Type Roof parallel PV Generator Surface 429.4 m²	East oriented part PV Modules 36 x LR5-72 HBD 520 M (v3) LONGI Solar; Inclination 10° Orientation East 172° Installation Type Roof parallel PV Generator Surface 92.0 m²
	
(c)	(d)
Second part of the roof PV system 168 units x LR5-72 HBD 520 M (v3) LONGI Solar; Inclination 10 ° Orientation North 353° Installation Type Roof parallel PV Generator Surface 429.4 m² (used two orientations)	West oriented part PV Modules 36 x LR5-72 HBD 520 M (v3) LONGI Solar; Inclination 10° Orientation West 262° Installation Type Roof parallel PV Generator Surface 92.0 m² (used two orientations for roof PV system №4).
	
(e)	(f)
Second part of the roof PV system 168 units x LR5-72 HBD 520 M (v3) LONGI Solar; Inclination 10 ° Orientation South 173° Installation Type Roof parallel PV Generator Surface 245.4 m² (used two orientations for roof PV system №3).	East oriented part PV Modules 36 x LR5-72 HBD 520 M (v3) LONGI Solar; Inclination 10° Orientation East 83° Installation Type Roof parallel PV Generator Surface 92.0 m² (used two orientations for roof PV system №4).
	
(k)	(l)
PV Modules 204 x LR5-72 HBD 520 M (v3) LONGI Solar Inclination 0° Orientation West 263° Installation Type Roof parallel PV Generator Surface 521.4 m²	West oriented part PV Modules 36 x LR5-72 HBD 520 M (v3) LONGI Solar; Inclination 10° Orientation West 263° Installation Type Roof parallel PV Generator Surface 92.0 m² (used two orientations for roof PV system №4).

Fig. 4. Models of 1–4 parts of PV system with main technical parameters installation PV-modules.



Fig. 5. Flow-chart of designed system 1st type.

configuration; in configuration MPP 1: 1 × 12; MPP 2: 1 × 12; MPP 3: 1 × 12 for west configuration.

- 3rd area Fig. 4 (e) and Fig. 4 (k) use 6 units PLENTICORE M G3 12.5 (battery option) Kostal with sizing factor 110.9% in configuration MPP 1: 1 × 16; MPP 2: 1 × 16 for south configuration; MPP 1: 1 × 16; MPP 2: 1 × 16 for north orientation.
- 4th area Fig. 4 (f) and Fig. 4 (l) use 2 units PIKO 17 – Kostal with sizing factor 110.1% in configuration MPP 1: 1 × 12; MPP 2: 1 × 12; MPP 3: 1 × 12 for east configuration; in configuration MPP 1: 1 × 12; MPP 2: 1 × 12; MPP 3: 1 × 12 for west configuration.

Grid-connected PV system with electrical appliances was presented in Fig. 6.

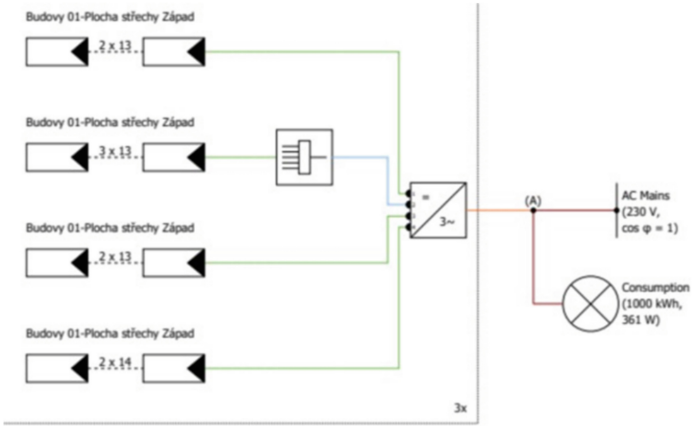


Fig. 6. PV system 2 type.

In paper is used typical load schedule for school 1000 m^2. For more detailed information better used collected data [8]. Flow-chart of presented system shown in Fig. 7. PV system still is not efficiency in Ukrainian conditions and can be improved due add battery storage system, because high level dependency from power grid. Battery storage systems will increase price. Simulation results of covered by PV system of school power supply needs presented in Fig. 8. Investments will be near $524,160.00 and presented in Fig. 10.

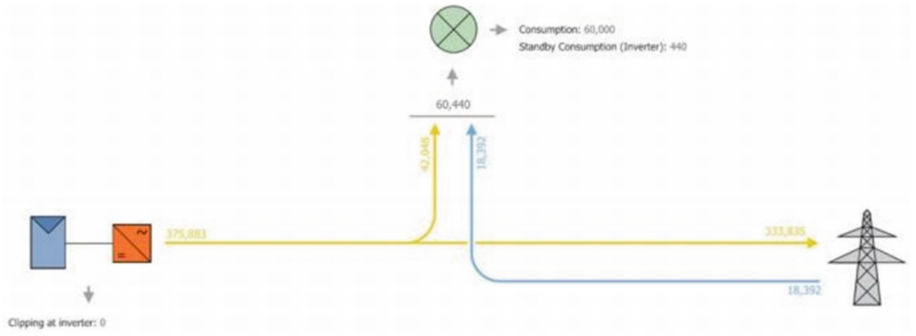


Fig. 7. Flow-chart of designed system 2 type.

Grid-connected PV system with electrical appliances is perfect for region in Ukraine, with short time period of power supply interruption (Central Ukraine). Surplus load mode can be used for particular appliances, for example boiler.

Power generation forecasting annual histogram, with take into account consumption is presented in Fig. 9.

In the future study will be design grid-connected PV system with electrical appliances and electrical vehicles and battery systems [8]. More case studies from various regions of Ukraine with different climatic and social conditions for better comparation end evaluation the effectiveness will be one of the directions of the future research. Maintenance and safety aspects of PV systems, especially in the context of deteriorated security conditions and power outages is crusial problem is Ukraine. For school is suggested better used every year full check and service of PV system. Simulations and modeling with more detailed scenarios that account for different climatic and operational conditions, profiles-load school (school with pool and without). Detailed economic analysis, covering installation costs, maintenance, and expected savings is difficult predict, because price and available equipment are changing.

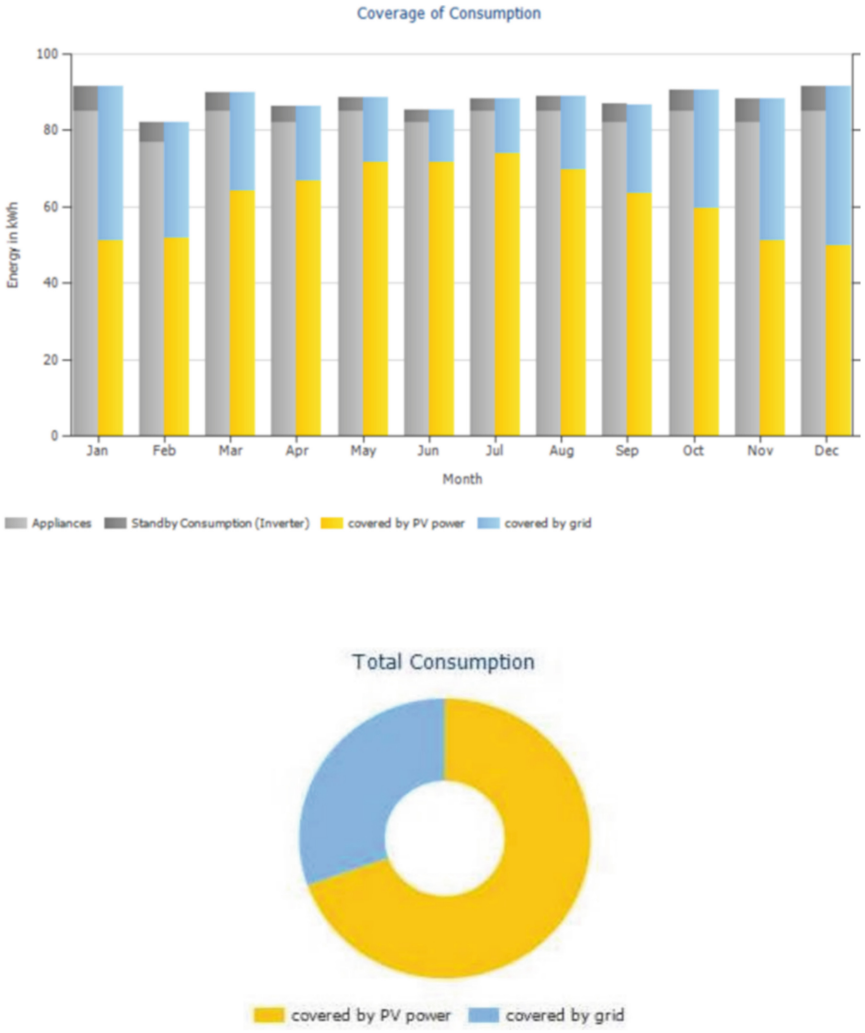


Fig. 8. Coverage consumption by PV system.

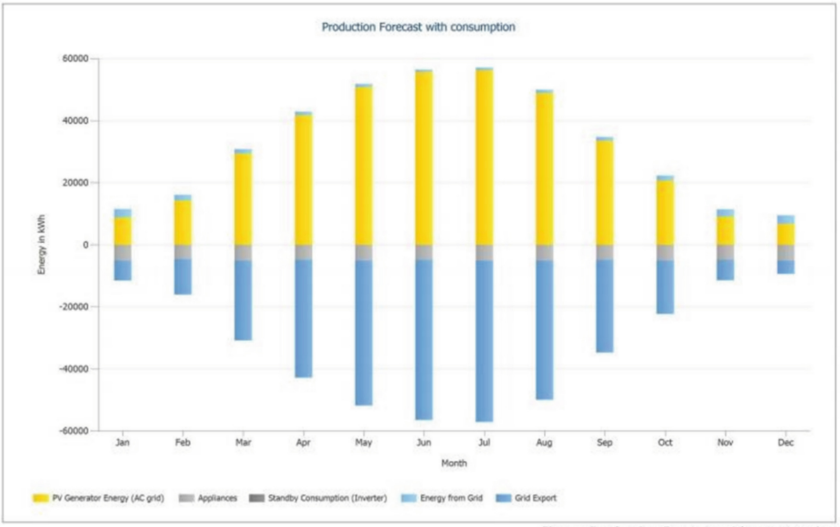


Fig. 9. Consumption school and PV system generation.

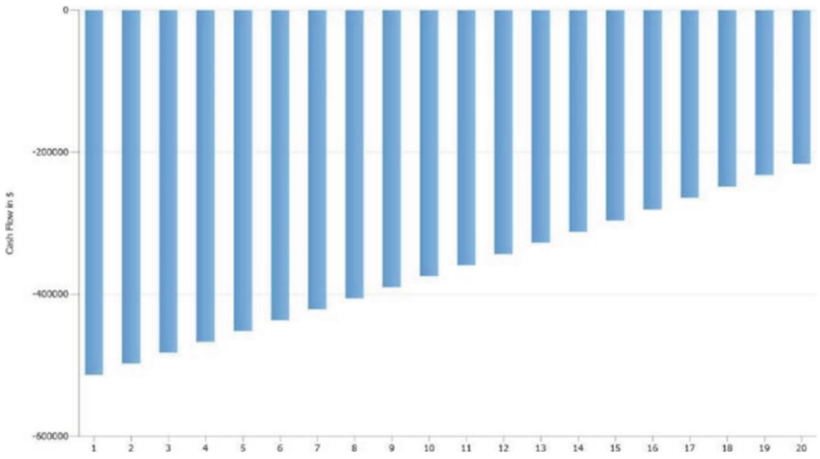


Fig. 10. Accrued Cash Flow (Cash Balance)

4 Conclusion

1. Analyze of current situation in energy sector of Ukraine shown relevancy and actuality of distributed energy sources developing in short-time future. Huge amount deficit of electricity in Ukrainian power system requires implement strict limitation for citizens. For example in Kyiv on 16 May the power supply interruption was more 12 h for particular districts, include schools, universities.

2. Distributed power sources benefits can be classified depending on usage, location and operation mode. For this case is very important to install an optimal PV system and correct operate. Ukrainian school is specific project, because it is not just for studying property, but it is very often using how shelter for refugees. Grid-connected PV system with electrical appliances and battery systems is more efficiency and useful for school.
3. PV system models and demand of school were simulated in PV*SOL Premium.

Acknowledgment. This paper was supported by MSCA4Ukraine 1233365, 24- PKVV-UM-006, 24-PKVV-UM-007.

References

1. Russia's biggest airstrike in weeks piles pressure on Ukraine's power grid. Source: Reuters Avaible online: https://www.nbcnews.com/news/world/russia-ukraine-war-airstrikes-power-grid-infrastructure-blackouts-kyiv-rcna151196
2. Source: ExPro. n June, Ukraine almost doubled its electricity imports Avaible online: https://ua-energy.org/uk/posts/ukraina-mynuloho-tyzhnia-narostyla-import-elektroenerhii-u-pivtora-raza
3. Bilozerova, L. Solar generation: the scale and geography of objects change. https://ua-energy.org/uk/posts/tryfonivska-ses-foto-dtek%202024
4. Kasic, Y. Energy Decentralization – Distributed Generation! (2023). https://iclub.energy/blog/yurij-kasich/tpost/fyz5ufdeg1-energetichna-detsentralzatsya-rozoseredz
5. Bezruchko, V., Buinyi, R., Dikhtyaruk, I., Miroshnyk, O., Myrhorod, D.: Installation of sectionalizers in a radial distribution networks to create an emergency islanded network powered by distributed generators during outages. In: 2023 IEEE 5th International Conference on Modern Electrical and Energy System (MEES), pp. 1–4. Kremenchuk, Ukraine (2023). https://doi.org/10.1109/MEES61502.2023.10402548
6. Belik, M., Rubanenko, O.: Technology optimisation of hybrid pv systems for covering energy needs of emergency shelters for ukrainian war refugees. E3S Web Conf. **472**, 01023 (2024). https://doi.org/10.1051/e3sconf/202447201023
7. Galushchenko, H.: The Ukrainian energy industry is increasing RES capacity and will become climate neutral. Ministry of Energy of Ukraine, published on January 26, 2024 https://www.kmu.gov.ua/news/herman-halushchenko-ukrainska-enerhetyka-naroshchuie-potuzhnosti-vde-i-stane-klimatychno-neitralnoiu
8. Energy audit report Secondary school of I-III degrees № 4 of Shevchenkivskyi district 27 Volzka St. https://mep.ecosys.com.ua/data/ea_report_school4.pdf
9. Abdelsattar, M., Ismeil, M.A., Aly, M.M., Saber Abu-Elwfa, S.: Analysis of renewable energy sources and electrical vehicles integration into microgrid. IEEE Access **12**, 66822–66832 (2024). https://doi.org/10.1109/ACCESS.2024.3399124