



**Conference Proceedings**  
**2023 IEEE International Conference**  
**on Environment**  
**and Electrical Engineering**  
**and 2023 IEEE Industrial and Commercial Power**  
**Systems Europe**  
**(EEEIC / I&CPS Europe)**  
**6 – 9 June, 2023, Madrid, Spain**

**Editor: Zbigniew Leonowicz**

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**Conference Record # 57605**  
**Part Number: CFP2351I-CDR    ISBN 979-8-3503-4742-5**

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IEEE IEEEIC 2023 is the 23<sup>rd</sup> annual conference, making it one of the largest, longest-running, professional networking and educational event of its kind in Europe.

On behalf of the organizing committee, we are honored and delighted to welcome you to the 23<sup>rd</sup> IEEE International Conference on Environment and Electrical Engineering and 7<sup>th</sup> Industrial and Commercial Power System Europe.

Our joint conferences must remain one of the major events of the IEEE in Europe, and must represent, even amid the COVID and War in Ukraine crisis, one of the largest web-gatherings of researchers and industry professionals in the world. We would like to acknowledge the technical sponsorships of three IEEE

International Societies: the **Electromagnetic Compatibility Society (EMC)**, the **Industrial Application Society (IAS)**, and the **Power and Energy Society (PES)**. We would also like to express our sincere gratitude to IAS for the financial support.

With more than 200 attendees from all around the world, our conference represents a unique opportunity for researchers, academics, engineers, and experts to present and exchange the latest information on the exciting and stimulating fields of electrical technology, energy, environmental engineering, smart grid, building automation, storage, e-mobility, etc.

Our technical program is rich and varied, with numerous technical oral sessions, as well as poster sessions each day.

We know that the success of a conference ultimately depends on the many people who have worked in planning and organizing both the technical program and supporting social arrangements. We therefore recognize the hard work of all the Chairs involved in the organization of a successful conference.

We hope that all the attendees will have a memorable and enjoyable time.

Warmest Regards.

*Redolfo Aranec    Luigi Martirano*



The Industrial and Commercial Power System Department (I&CPS) is a department of the Industry Application Society (IAS) of the Institute of Electrical and Electronic Engineers (IEEE). The scope of the Industrial and Commercial Power Systems Department includes all matters within the scope of the Industry Application Society relating to the technology of

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- 3,422 Student Branches at colleges and universities in over 100 countries
- 2,600 Student Branch chapters of IEEE technical societies
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IEEE:

- Has 39 technical Societies and seven technical councils representing the wide range of IEEE technical interests
- More than 5 million documents in the IEEE Xplore® digital library, with more than 8 million downloads each month
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- Has over 1,200 active standards and more than 650 standards under development
- Publishes approximately 200 transactions, journals, and magazines
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Guglielmo Marconi (1920, for radio telegraphy)

William Shockley (1980, for junction, analog, and junction field-effect transistors)

Andrew S. Grove (2000, for pioneering research in metal oxide semiconductor devices and technology)

Gordon E. Moore (2008, for pioneering technical roles in integrated-circuit processing, and leadership in the development of MOS memory, the microprocessor computer and the semiconductor industry)

Mildred Dresselhaus (2015, for leadership and contributions across many fields of science and engineering)

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- to avoid injuring others, their property, reputation, or employment by false or malicious action;
- to assist colleagues and co-workers in their professional development and to support them in following this code of ethics.

## List of Papers

| ID | Title                                                                                                                                                | Authors (* Corresponding Author)                                                                                                                    |
|----|------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| 2  | Energy Management System for a Hybrid Wind Solar Battery Based Standalone Microgrid                                                                  | Ahmed Aghmadi; Osama Mohammed*; Hossam Hussein                                                                                                      |
| 3  | Impact of ultrafast EV charging stations on the electrical distribution grid: a case study in Terni                                                  | Marco Antonio Bucarelli*; Alberto Geri; Marco Maccioni; Fabio Massimo Gatta; Tommaso Bragatto; Marco Paulucci                                       |
| 5  | Corona Activity on Single-circuit Overhead Transmission Lines under Variable Altitude                                                                | Evanthia I. Bousiou*; Pantelis Mikropoulos; Vasilios Zagkanas                                                                                       |
| 6  | A Novel Hybrid Single-Phase Modular Multilevel Inverter Topology with Enhanced Number of Levels Per Number of Devices                                | Mohammad Farsijani*; Sohrab Abbasian; Hossein Hafezi                                                                                                |
| 8  | Long-term Hourly Cooling Load Forecasting through Combination of Global-domain and Sub-domain                                                        | Hangyu Che*; Masafumi Kinoshita; Shiyu Lu                                                                                                           |
| 9  | Comparative analysis of the energy performance of floating and ground-mounted photovoltaic power plants                                              | Arsenio Barbon; Luis Bayon*; Javier Aparicio-Bermejo; Covadonga Bayon-Cueli                                                                         |
| 10 | Emerging concept of human centric lighting in literature review                                                                                      | Tuğçe Kazanasmaz*; Fatma Busra Kose; Gokmen Tayfur                                                                                                  |
| 13 | Voltage-current based algorithm for the on-line estimation of equivalent internal resistance of Lithium-Cobalt-Oxide cells at different aging levels | Massimo Ceraolo; Giovanni Lutzemberger*; Claudio Scarpelli; Natascia Andrenacci; Manlio Pasquali                                                    |
| 14 | Operation of Hydrogen Storage Units as Shared Energy Storage in Renewable Enriched Systems: An IGDT Approach                                         | Farid Hamzehaghdam ; Manthila Wijesooriya Mudiyansele; Mousa Marzband*; Behnam Mohammadi-Ivatloo; Mehdi Abapour; Mohammad Sadegh Javadi Estahbanati |
| 15 | Grid code effect on wind farm power management and data analysis (Nouadhibou Mauritanian case study)                                                 | Taghy Taghy*                                                                                                                                        |
| 16 | A centralized automatic generation control for island systems dominated by inverter-based resources                                                  | Apostolos Papakonstantinou*                                                                                                                         |
| 17 | Literature Review On Smart Windows In Terms Of Daylight Performance, Visual Comfort and Human Perception                                             | Ilgin Coğul*; Tuğçe Kazanasmaz                                                                                                                      |
| 18 | Initial Assessment of Electrical Flexibility of Combustion-Based District Heating Systems                                                            | Lorenza Elorza-Uriarte; Roberto Rocca*; Itziar Zubia; Daniele Farrace; Riccardo Toffanin; David Miguel Rivas-Ascaso                                 |
| 19 | Fabrication and Characterization of Electronic Devices based on Ferrocene Heterostructures                                                           | María Elena Sánchez Vergara*; Emiliano Toledo Dircio; Octavio Lozada-Flores ; Roberto González-Ojeda; Leon Hamui                                    |

|    |                                                                                                                      |                                                                                                                  |
|----|----------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|
| 20 | Study of the Grounding Behavior of Gas-Insulated Switchgear (GIS Type Substations) Submitted to Lightning            | Diego Oliz*; Daniel S Gazzana                                                                                    |
| 21 | Identification of Integrated Management System in Electricity Business Sector                                        | Irvan Khairil Solin*                                                                                             |
| 22 | Numerical Modeling of Switching Processes in Magnetically Controlled MEMS Switches                                   | Sergey Karabanov*; Dmitriy Suvorov; Dmitry Y Tarabrin                                                            |
| 23 | IoT-based Battery Monitoring System for State-of-Charge Estimation                                                   | Farhan Shams*                                                                                                    |
| 24 | The Equivalent Models in the Sequence Domain of Grid-Forming Converters based on the Virtual-Flux Orientation        | Juan Dolado*; Santiago Arnaltes Gomez; Joaquín Eloy-García; Jose Luis Rodriguez Amenedo                          |
| 27 | Motor Load Models for Fault-Induced Delayed Voltage Recovery Studies in Bulk Transmission Systems                    | Mark Halpin*                                                                                                     |
| 28 | Optimal off-grid photovoltaic production in developing countries during critical months by using optimum tilt        | Monica Chinchilla-Sánchez*; Jose Luis Sanmartín; Jorge Martinez Crespo; Ulpiano Ruiz-Rivas Hernando              |
| 29 | Electric Vehicle Battery Charging Model using Photovoltaics and Energy Storage Systems                               | Francisco Duro; José Baptista*; Carlos Serôdio                                                                   |
| 30 | Developing Optimization-Based Inverter Models for Short Circuit Studies                                              | Thabiso Mabote*; Jose Tabarez; Arthur Barnes; Adam Mate; Eduardo Cotilla-Sanchez                                 |
| 31 | Frequency Stability Enhancement in Low-Inertia Power System Using an Optimal Control Scheme                          | Ola Ali*; Osama Mohammed                                                                                         |
| 32 | Analyzing Closed-loop Control Methods in Domino Resonant Inductive Wireless Power Transfer System                    | Bayandy Sarsembayev; Seyed Saeid Heidari Yazdi*; Sadjad Shafiei; Mostafa Kermani; Almaz Saukhimov; Mehdi Bagheri |
| 33 | The Role of Renewable Energy Generation in Electric Vehicles Transition and Decarbonization of Transportation Sector | Qais Ali*                                                                                                        |
| 34 | Optimal Power Dispatch and Load Scheduling For Multi-Energy Community With Fuel Cell Combined Heat and Power         | Leehter Yao*; J. C. Teo                                                                                          |
| 35 | Virtual Instrumentation and Torque Estimator for the Drive and Control of the Switched Reluctance Machine            | Ghunter P Viajante*; Ricardo Tirone; Luciano Coutinho; Marcelo Escobar; Eric Nery                                |
| 37 | Stochastic Optimization of an Active Network Management Scheme for a DER-Rich Network comprising Various Aggregators | Olusegun A. Adeniji*; Behzad Kazemtabrizi                                                                        |
| 39 | On the CIM Modelling Approach for the Frequency Estimation of a Power System Restoration Process                     | Roberto Benato; Sebastian Dambone Sessa; Francesco Sanniti*                                                      |

|    |                                                                                                                                   |                                                                                                       |
|----|-----------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
| 40 | Effectiveness of BESS in Improving Frequency Stability of an Island Grid                                                          | Hung Cuong Nguyen*; Quoc Tuan Tran; Yvon Besanger                                                     |
| 41 | Enhance Demand Response Participants Performance Using a Personalized Recommendation Method                                       | Cátia Silva; Pedro Faria; Zita Vale*                                                                  |
| 42 | Demand Response-based Model for an Energy Community Considering Members and Electric Vehicles Participation                       | Ruben Barreto; Luis Gomes; Zita Vale*                                                                 |
| 43 | Joint Optimization of Production and Maintenance for Effective Manufacturing Using a Genetic Algorithm                            | Bruno Mota; Pedro Faria*; Carlos Ramos                                                                |
| 44 | Hybrid System Optimization Model for Hydrogen Production, Case Study: South Africa                                                | Esmeralda E Mukoni*; Karen Garner; Chantelle Y Van Staden                                             |
| 45 | Negative sequence power based fault detection scheme for power islands during unbalanced faults                                   | Deepika Chhetija*; Imran Khan; Zakir H Rather; Suryanarayana Doolla                                   |
| 47 | Frequency support technologies analysis for WECs in the isolated Grid System of Gran Canaria                                      | Carolina Nicolás-Martín*; David Santos-Martin; Monica Chinchilla-Sánchez; Jorge Martínez-Crespo       |
| 48 | Consumer-Side Analysis of Distributed Generation on the Marginal Cost through Energy Losses                                       | Renan J Orellana*; Miguel Udaeta                                                                      |
| 49 | 1D control model of a hydrogen-powered vehicle for race strategy optimization                                                     | Massimiliana Carello*; Matteo De Carlo; Giuseppe Pio Tempone                                          |
| 50 | Short-term Forecasting for Load and Solar Generation in Electrical Distribution Networks                                          | Quoc Tuan TRAN*; Thien-Phong Tran; The Tran Hoang; Thanh-Son TRAN; Van Phuong Vo                      |
| 51 | Vibration Analysis Method of Windings for Transformer Condition Monitoring                                                        | C. Linhares*; Helena Lopes; C. Coutinho; H. Mendes; J. F. B. Meireles                                 |
| 52 | Numerical simulations of polymeric dielectric polarization current: sensitivity analysis                                          | Fabio Ragazzi*; Arturo Popoli; Giacomo Pierotti; Andrea Cristofolini; Paolo Seri                      |
| 54 | FEVER - Fem Electrothermal solver: application to an HVDC joint                                                                   | Giacomo Pierotti*; Arturo Popoli; Fabio Ragazzi; Bassel Diban; Andrea Cristofolini; Giovanni Mazzanti |
| 55 | Inductive interference from HVAC power lines on metallic pipelines using FLARE – Finite eLement Analysis foR Electromagnetics     | Arturo Popoli*; Fabio Ragazzi; Giacomo Pierotti; Andrea Cristofolini                                  |
| 57 | Case study: Optimization tools for the operational dispatch of a hybrid power generation system to reduce diesel fuel consumption | Daniel F Sempértegui-Tapia*; Cesar Alberto Ayma-Ramos; Filiberto Soto Encinas; Renan J Orellana       |
| 58 | Day-Ahead Residential Customer Load Forecasting Using Prophet                                                                     | Yahia Baghzouz*                                                                                       |
| 59 | Optimization Solutions in Energy Management Systems for Public Smart Lighting Applications                                        | Hector F. Chinchero*; Alfonso Marchan                                                                 |

|    |                                                                                                                                              |                                                                                                                                          |
|----|----------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| 60 | Misalignment-Resilient Control Scheme for Bidirectional Power Transfer in IPT Systems                                                        | Francisco Javier López-Alcolea*; Alfonso Parreño-Torres; Emilio José Molina-Martínez; Javier Vázquez; Pedro Roncero                      |
| 61 | LSTM-based Network for Current Harmonic Distortion Time Series Forecasting                                                                   | Joaquin Garrido-Zafra*; Aurora Gil-De-Castro; Antonio Calleja-Madueno; Matias Linan-Reyes; Isabel M. Moreno-Garcia; Antonio Moreno-Munoz |
| 62 | Sharing-Cost Factors for a Community of PV Prosumers with Battery Storage                                                                    | Jorge Barba Marcos*; Sebastian Martin                                                                                                    |
| 63 | Adaptive Model Predictive Control for Large-scale Coordinated PEV Recharging                                                                 | Francesco Liberati*; Emanuele De Santis; Alessandro Di Giorgio                                                                           |
| 64 | Stochastic Programming Versus Chance-Constrained Optimization for Optimal Rescheduling of Microgrids in Hierarchical Multi-Microgrid Systems | Seyed Farhad Zandrazavi*; Alejandra Tabares; John Fredy Franco; Miadreza Shafie-Khah; Joao Soares; Zita Vale                             |
| 65 | Co-Simulation Strategy for Photovoltaic Power Prediction and Validation of Digital Twin                                                      | Daud Mustafa Minhas*; Muhammad Usman; Georg Frey                                                                                         |
| 67 | Impact of Distributed Energy Resources on Power Distribution Systems: A Simulation Study on Energy Transition                                | Leonardo N Silva*; Gustavo S Djambolakdjian; Fábio F. Vidor; Daniel S Gazzana; Renato G. Ferraz                                          |
| 69 | Frequency Measurement Techniques for Power System Protection and Control Applications                                                        | Farnam Hojatpanah; Firouz Badrkhani Ajaei*                                                                                               |
| 70 | Performance and Economic Comparison of String and Central Inverter Systems                                                                   | Sonia Leva*; Fabio Peng Hu; Enrico Lamanna                                                                                               |
| 72 | Probabilistic Microgrid Economic Dispatch via Economic Model Predictive Control Considering Weather and Load Data Uncertainty                | Maral Shadaei*                                                                                                                           |
| 74 | Inclusion of HVDC links in the Paduan three-phase power flow (PFPD_3P)                                                                       | Roberto Benato; Giovanni Gardan; Luca Rusalen*                                                                                           |
| 75 | Fuse-based protection system in a DC-microgrid for fast-charging applications: sizing and implications                                       | Riccardo Ramaschi*; Sonia Leva; Alberto Gobessi; Marco Mauri                                                                             |
| 76 | Impact of energy pricing regimes on production schedules under solar-hydro hybridization                                                     | Jiehong Kong*; Alexandra J Sheppard; Hanne Nøvik; Øyvind Engelstad; Bjørnar Fjellidal; Gro Klæboe; Hans Ivar Skjelbred                   |
| 77 | Decentralized Wind Power Plants Contribution to Primary Frequency Control                                                                    | Angel Molina-Garcia*; Ana Fernandez-Guillamon; Guillermo Martinez De Lucas; Jose Ignacio Saras A Moreno                                  |
| 79 | Daylight Performance and Lighting Energy Savings of Amorphous and Crystalline Silicon Solar Cells in an Architecture Studio                  | Aybüke Taşer*; Tuğçe Kazanasmaz                                                                                                          |
| 80 | Partial Discharge Diagnostics of High Voltage Instrument Transformers – Case study                                                           | Michał Kunicki*; Ondřej Kabot; Michał Koziół                                                                                             |

|    |                                                                                                            |                                                                                                                                    |
|----|------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|
| 81 | Evaluation of Solar and Lunar Eclipse Impacts on Danish Power System as a Case Study                       | Hamed Kheirandish Gharehbagh; Sajjad Miralizadeh Jalalat; Navid Bayati*; Thomas Ebel                                               |
| 82 | A Theoretical Analysis of the Direct Flux Control Technique for Inter-Turns Short-Circuits in PMSMs        | Fabio Corti*; Francesco Grasso; Marco Pratelli; Luca Pugi; Emanuele Grasso; Matthias Nienhaus                                      |
| 83 | Potential of Morocco in Energy Generation from Agricultural Residues                                       | Meisam Mahdavi*; Augustine Awafo; Konrad Schmitt; Francisco Jurado; David Vera                                                     |
| 84 | Effect of Demand Side Pattern on Feeder Switching and Reactive Power Compensation in Distribution Networks | Meisam Mahdavi*; Konrad Schmitt; Francisco Jurado; Augustine Awafo                                                                 |
| 85 | Experimental Analysis Of The Effect Of Static Yaw Error On Wind Turbine Nacelle Anemometer Measurements    | Davide Astolfi*; Linyue Gao; Ravi Pandit; Jiarong Hong                                                                             |
| 86 | Modelling battery packs of real-world electric vehicles from data sheet information                        | Raimondo Gallo; Tommaso Monopoli; Marco Zampolli; Rémi Jacques Philibert Jaboeuf; Paolo Tosco; Alessandro Aliberti; Edoardo Patti* |
| 87 | A Numerical Study of the Performance of Rod Type Grounding                                                 | Konstantinos Koutras*; Georgios Peppas; Eleftheria Pyrgioti                                                                        |
| 88 | Digital Real-Time Power System Co-simulation via Distributed Transmission Line Model                       | Luca Barbierato*; Steffen Vogel; Daniele Schiera; Enrico Pons; Lorenzo Bottaccioli; Antonello Monti; Edoardo Patti                 |
| 89 | A Proactive Stochastic Framework for Cyber-Physical Power Systems Security                                 | Arturo Bretas*                                                                                                                     |
| 90 | Impact of Permanent Magnet Aging on the Performance of Synchronous Motors for Traction Applications        | Vasco P. Melo; Pedro P. C. Bhagubai; João F. P. Fernandes*; Paulo Branco                                                           |
| 91 | Renewable Source Power Quality in Italian Grid by Paduan Three-Phase Power Flow PFPD_3P                    | Roberto Benato; Giovanni Gardan; Luca Rusalen*                                                                                     |
| 92 | PSFB DC-DC Converter Control Technique for DC Microgrid Application                                        | Mohd Alam*                                                                                                                         |
| 94 | Voltage Control of Microgrid using Co-Simulation between Powerfactory and FMUs in Matlab                   | Tri Minh Le*; Quoc Tuan Tran; Yvon Besanger                                                                                        |
| 95 | Renewable Power Routing from a DC Microgrid to an Industrial Cluster                                       | Andrea Alessia Tavagnutti; Alessandro Cecon; Daniele Bosich*; Giorgio Sulligoi                                                     |
| 96 | Application of Hall Position Sensor in Control and Position Estimation of PMSM- A Review                   | Milad Akrami; Ehsan Jamshidpour*; Vincent Frick                                                                                    |
| 97 | A comparative study on the dielectric properties of mineral oils and natural esters                        | Andrés Montero Romero*; Diego García; Belén García De Burgos; Juan Carlos Burgos                                                   |
| 98 | A Ground Fault Location Method for DC Railway Systems                                                      | Jose Manuel Guerrero; Daniel Serrano-Jimenez; Kumar Mahtani; Carlos A. Platero*                                                    |

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|-----|--------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|
| 99  | Ground Fault Detection Method for DC Microgrids Based on Switching Grounding Connections                                                         | Jose Manuel Guerrero; Itxaso Aranzabal; Julen Gomez-Cornejo; Pablo Eguia; Carlos A. Platero*                                     |
| 100 | Autoencoders for Anomaly Detection in Electricity and District Heating Consumption                                                               | Zahraa Khais Shahid*; Saguna Saguna; Christer Åhlund                                                                             |
| 101 | AC Ground Fault Location Technique for Variable Speed Drives                                                                                     | Jose Manuel Guerrero; Daniel Serrano-Jimenez; Vanesa Valiño; Carlos A. Platero*                                                  |
| 102 | Control of Hydrogen Storage Systems for Primary Frequency Response and Inertia Emulation                                                         | Dimitrios Zarras*; Apostolos Papakonstantinou; Stavros Papathanassiou                                                            |
| 103 | Microgrids Provision of Frequency Response to Low-Inertia Grids                                                                                  | Maad Al Owaifeer*; Youssef Awda; Mohamed Abido                                                                                   |
| 104 | A Review of Non-Wires Alternatives to Distribution Network Reinforcements: Comparison of Utility and Investor Perspectives                       | Carlos García-Santacruz*; Alejandro Marano-Marcolini; José L. Martínez-Ramos                                                     |
| 105 | Five-phase Harmonic-Excited Synchronous Machine for Hybrid Vehicle Application                                                                   | Sukanya Kamboj*; Gurakuq Dajaku; Dieter Gerling                                                                                  |
| 106 | A New Loss Minimization Model for Coordinated Network Reconfiguration, Capacitor Placement and DG Allocation Under Variable Loading Conditions   | Meisam Mahdavi*; Sasa Djokic; Francisco Jurado; Augustine Awafo                                                                  |
| 107 | Parametric simulations to evaluate occupants' behavior incidence on building energy performance – A Passive House case study                     | Massimiliano Manfren; Maria Cristina Tommasino; Lamberto Tronchin*                                                               |
| 108 | Enabling optimal vehicle-to-grid operation in a DC microgrid                                                                                     | Francesca Marasciuolo*; Maria Dicorato; Giuseppe Forte; Maria Chiara Cavarretta; Davide De Michino                               |
| 109 | High-Voltage Insulator Surface Pollution Classification Using Insulator Type-Specific CNNs                                                       | Aibek Abilgazym; Amin Zollanvari; Mehdi Bagheri*                                                                                 |
| 110 | Rigorous Automated Verification of Protection Systems in LV Distribution Grids                                                                   | Ahmed Nagy A Mansour*; Samuele Grillo; Matteo Rossi; Enrico Ragaini                                                              |
| 112 | A Co-simulation Procedure for Optimal Reactive Power Control in Active Distribution Networks                                                     | Gioacchino Tricarico*; Raju Wagle; Jesús Castro Martínez; Francisco Gonzalez-Longatt; Giuseppe Forte; Maria Dicorato; Jose Rueda |
| 113 | A Time-series Hosting Capacity Assessment of the Maximum Distributed Energy Resource Production                                                  | Gioacchino Tricarico*; Francisco Gonzalez-Longatt; Francesca Marasciuolo; Oleksandra Ishchenko; Giuseppe Forte; Maria Dicorato   |
| 114 | Design of a digital architecture supporting blockchain-based traceability within a Net-Zero Energy Factory. The case study of a German carpentry | Pio Alessandro Lombardi*                                                                                                         |
| 115 | Resonance Model Comparison for High-Frequency AC Link Three-port Converter                                                                       | Eduardo R Vasquez Mayen*; Emmanuel De Jaeger; Julien Allard                                                                      |
| 116 | Resilience Oriented Planning for Multi-energy Microgrids in an Urban Area                                                                        | Linan Zhang*; Zihang Dong; Xi Zhang; Ning Zhang; Goran Strbac                                                                    |

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|-----|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 117 | Ice Sleeves on Overhead Power Lines: a Deep Learning Approach for Semantic Segmentation                                                                                | Alberto Maldarella*; Vincenzo Rotella                                                                                                                                                   |
| 118 | Numerical analysis of a concentrating solar power plant integrating solid thermal storage systems for biofuel production                                               | Alessandro Buscemi*; Stefania Guarino; Valerio Lo Brano                                                                                                                                 |
| 119 | Clustering Based Method anomaly definition in Electric Vehicles charging curves                                                                                        | Silvana Matrone*; Emanuele Giovanni Ogliari; Sonia Leva; Federico Devalle; Federico Vitti; Giuseppe Gilberto                                                                            |
| 120 | Energy Optimization System based on storage potentials of distributed Electric Vehicles                                                                                | Milad Riyahi*; Jesús Fraile-Ardanuy; David Jiménez; Sandra Castaño-Solis; Daniel Fernández-Muñoz; Juan Ignacio Pérez-Díaz; Alvaro Gutierrez                                             |
| 121 | Industrial demand side flexibility: the case of the metallurgy sector in Spain.                                                                                        | Erick Andres Dorado Galatoire*                                                                                                                                                          |
| 122 | Comparative Performance analysis of different PV plants in Italy                                                                                                       | Emanuele Giovanni Ogliari*; Sonia Leva; Marcello Polenghi; Luca De Ciecchi                                                                                                              |
| 123 | Transformer Health Monitoring via Synchrophasors                                                                                                                       | Giancarlo Paramo*; Arturo Bretas                                                                                                                                                        |
| 124 | Preliminary design of eddy current brake to improve sustainable mobility                                                                                               | Daniel Pacheco; Ettore Bianco*; Massimiliana Carello; Daniela Maffiodo                                                                                                                  |
| 125 | In situ Wideband Frequency Response Measurements of a Distribution Transformer Using Pseudo-Random Impulse Sequence Perturbation                                       | Daniel Banks; Johannes Bekker*; Fredrick M Mwaniki; Hj Vermeulen                                                                                                                        |
| 126 | Influence of Negative-Sequence Control under Converter-Interface-based Generation in Distance Protection Relays                                                        | Luis Azuara*; Ricardo Granizo Arrabé; Santiago Arnaltes Gomez; Jose Luis Rodriguez Amenedo                                                                                              |
| 127 | Optimizing Distributed Generation Sizing and Siting using Particle Swarm Optimization: A Comparative Study                                                             | Eihab E. E. Ahmed; Gokturk Poyrazoglu*                                                                                                                                                  |
| 128 | Feasibility study of floating photovoltaic panels in the Adriatic Sea                                                                                                  | Jacopo Agnelli; Antoine Dib; Aldo Pierattini; Nicholas Fantuzzi*                                                                                                                        |
| 129 | A test bench for the production of green hydrogen and its traceability and certification using blockchain technology                                                   | Salvatore Ruffino*; Fabio Massaro; Eleonora Riva Sanseverino; Mariano G Ippolito; Monica Santamaria; Pierluigi Gallo; Marco Ferraro; Giuseppe Sciumè                                    |
| 130 | Stability Assessment in Power Systems with High Penetration of Converter-based Generation                                                                              | Jesús Castro Martínez*; Santiago Arnaltes Gomez; Jose Luis Rodriguez Amenedo; Francisco Javier Renedo Anglada; Edgar Nuño Martínez; Macarena Martín Almenta; Sergio Martínez Villanueva |
| 131 | Optimum operational planning of wind-integrated power systems with embedded Multi-terminal High Voltage Direct Current Links using the Flexible Universal Branch Model | Siti K Hamzah*; Behzad Kazemtabrizi                                                                                                                                                     |

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|-----|--------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| 132 | Water as a pivotal resource for the environmentally conscious management of bus fleets in Europe                                                 | Maria Vittoria Corazza*; Matthew Robinson                                                                                                    |
| 133 | A Semi-Analytical Approach to Calculate Lightning EM Fields Considering Channel Tortuosity                                                       | Massimo Brignone; Martino Nicora*; Daniele Me-striner; Renato Procopio; Carlo Petrarca; Alessandro Formisano; Sami Barmada; Federico Delfino |
| 134 | High Gain Isolated Switched-Boost DC-DC Con-verter for PV Application                                                                            | Hazem Meshael; Ahmad Elkhateb*; Robert Best                                                                                                  |
| 135 | Integrated Planning of Active Distribution Systems and Charging Stations for Plug-in Electric Vehicles Considering the Vehicular Traffic Network | Mario A Mejia ; Leonardo Macedo*; John F. Fran-co; Gregorio Muñoz-Delgado; Javier Contreras                                                  |
| 136 | Underwater and In-Air IPT-CPT Wireless Power Transfer Performance Comparison: A Simulation Study                                                 | Sadjad Shafiei*; Seyed Saeid Heidari Yazdi; Mo-stafa Kermani; Almaz A. Saukhimov; Arsalan Hekmati; Mehdi Bagheri                             |
| 137 | Assessing the Grid Impact of Renewable Energy Communities in a Small Island                                                                      | Gaetano Zizzo*; Salvatore Favuzza; Mariano G Ippolito; Liliana Mineo; Rossano Musca; Anto-nino Barberi                                       |
| 138 | Short-term energy forecasting for public education-al institution                                                                                | Aleksandra Zlatkova*; Dimitar Taskovski; Zivko Kokolanski; Bodan Velkovski                                                                   |
| 139 | Experimental Characterisation of the Dynamic Me-chanical Properties of Pressboard                                                                | C. Linhares*; Vítor Carneiro; Helena Lopes; J. F. B. Meireles; H. Mendes                                                                     |
| 140 | Impact of the Transformer Stray Capacitances on the Ground Mode Current in Uearthed OHL Net-works: Analysis of the Travelling Waves Propaga-tion | Gabriele Biasiotti; Sebastian Dambone Sessa; Francesco Sanniti*; Simone Talomo                                                               |
| 141 | Fairness and reward in Energy Communities: game-theory versus simplified approaches                                                              | Davide Fioriti*; Tommaso Ferrucci; Davide Poli                                                                                               |
| 142 | A Real-Time Cycle Counting Method for Battery Degradation Calculation in MILP Models                                                             | Riccardo Nebuloni*; Lorenzo Meraldi; Luca Moretti; Valentin Ilea; Cristian Bovo; Alberto Ber-izzi; Pietro Raboni                             |
| 143 | Implementation of a supervisory control and data acquisition for a biaxial photovoltaic tracker by means of a low cost PLC Zelio                 | Domenico Curto*; Francesco Maria Raimondi; Vincenzo Franzitta; Andrea Guercio; Malik Ali Judge                                               |
| 144 | Distributed Demand Management Considering Thermal and Service-based User Comfort Under Forced Curtailment                                        | Alberto De Villa*; Michael Angelo Pedrasa                                                                                                    |
| 145 | Provision of Flexibility Services to the Distribution System Operator by Local Energy Communities                                                | Emely Cruz-De-Jesús*; Jose Luis Martínez-Ramos; Alejandro Marano-Marcolini; Carlos Gar-cía-Santacruz                                         |
| 146 | A Non-Intrusive Load Disaggregation Tool based on Smart Meter Data for Residential Buildings                                                     | Giovanni Baglietto*; Andrea Vinci; Stefano Mas-succo; Federico Silvestro; Francesco Conte                                                    |

|     |                                                                                                                                         |                                                                                                                                                       |
|-----|-----------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| 147 | Optimal sizing and placement of DFIG Wind Farm for Line Loss Reduction and Volt/Var Control in Distribution Network                     | Hocine Bouzina*; Sid Ahmed Tadjer; Fathia Chékired; Mohamed Boudour; Laurent Canale                                                                   |
| 148 | Key Stability Issues in a Power Hardware-In-the-Loop Experiment: Let's Make it Converge                                                 | Giorgio Benedetto; Andrea Mazza; Enrico Pons*; Ettore Bompard                                                                                         |
| 149 | A PI-MPC based Dual-loop Controller for Grid Forming Inverters                                                                          | Imran Khan*; Suryanarayana Doolla                                                                                                                     |
| 150 | Assessing the Impact of Eco-ADAS Systems on Vehicle Fuel Consumption and Emissions at Signalised Intersections                          | Mario Marinelli*; Mariano Gallo                                                                                                                       |
| 152 | Application of Post Occupancy Evaluation method on urban lighting design on case studies                                                | Marina Bonomolo*; Giacomo Salvadori; Michele Rocca; Giulia Lavinia Prizzi; Marco Giuseppe Petix; Vincenzo Castiglia; Francesco Leccese; Marco Beccali |
| 153 | Energy and Economic Comparison of Virtual and Physical Power Sharing                                                                    | Francesca Oliva*; Martina Moretti; Elena Gallo; Roberto Faranda                                                                                       |
| 155 | Assessing the Levelized Cost of Hydrogen Production in a Renewable Hydrogen Community in South Italy                                    | Alessandro Ciano*; Livio De Santoli                                                                                                                   |
| 156 | Impact of Electric Vehicle Charging on Voltage and Current Harmonics at the Point of Common Coupling                                    | Seyed Mahdi Miraftebzadeh*; Michela Longo; Dejan Pejovski; Morris Brenna; Marco Pasetti                                                               |
| 157 | Temporal Fusion Transformer for Day-Ahead Wind Power forecasting in the South African Context                                           | Liaan L Van Heerden *; HJ Vermeulen; Chantelle Y Van Staden                                                                                           |
| 158 | Collective Self-Consumption in Smart Buildings: a Case Study of the Lightness Project                                                   | Riccardo Trevisan*; Emilio Ghiani; Raphaëlle Papa; Sara Ruffini; Omar Caboni                                                                          |
| 160 | Investigatament of Machine Learning Classifiers for Diagnostics of Induction Motors                                                     | Nikolay Djagarov*                                                                                                                                     |
| 163 | Management of a Local Multi-Source Energy System in a Research Centre based on self-PV Generation and Electric Vehicles                 | Sandra Castaño-Solis*; Daniel Fernandez-Munoz; Jesús Fraile-Ardanuy; Alvaro Gutierrez; Giuseppe Conti; David Jimenez; Juan Perez Diaz                 |
| 164 | Harmonic Compensation in Ship Power System Using Peak Detection Control Strategy Based Shunt Active Power Filter                        | Nikolay Djagarov*                                                                                                                                     |
| 165 | Meta-Parametrization of Photovoltaic Module Technologies for a Comprehensive Evaluation of Solar Energy Projects in Road Infrastructure | Rene A Barrera-Cardenas*; Jon Are Suul; Bendik Torsater                                                                                               |
| 166 | Utility-Scale Solar Power Forecasting: Single-Step vs. Multi-Step Feed Forward Neural Networks                                          | Armand A Du Plessis*                                                                                                                                  |
| 168 | Real-time Electricity Market Price Prediction using Improved ARIMA Model                                                                | Mohamed Abido*                                                                                                                                        |

|     |                                                                                                                                        |                                                                                                              |
|-----|----------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|
| 169 | State Estimation of Electrical Grids via Neural Networks                                                                               | Maad Al Owaifeer*; Abdulrahman Katranji; Abdulrahman Taher                                                   |
| 170 | GaN-HEMTs-based Converter for Solar Power Tower Application in Harsh Weather Environment: Performance Evaluation                       | Mohamed Abido*                                                                                               |
| 172 | Development of a mobile app for early warnings in aquaculture farms: Identification end-user needs                                     | Tena Bujas*; Nikola Vladimir; Marija Koričan; Manuela Vukić; Vladimir Soldo; Zdenko Tonković                 |
| 173 | Thermal Building Models for Energy Management Systems                                                                                  | Benjamin Matthiss*                                                                                           |
| 174 | Voltage Optimization in Distribution Networks using EV Parking Lots and PV systems as flexibility options                              | Michele De Santis*; Anna Rita Di Fazio; Mario Russo; Tohid Harighi; Alberto Borghetti                        |
| 177 | A comparative study of Integer Order PID, Fractionalized Order PID and Fractional order PID controllers on a class of stable system    | Abdelhakim Idir*; Akroum Hamza; Sid Ahmed Tadjer; Laurent Canale                                             |
| 178 | Multi-Area Optimal Power Flow Problem Through Parallel Processing                                                                      | Lucas C Yamaguti*; Juan Home-Ortiz; Mahdi Pourakbari-Kasmaei; Jose R Sanches Mantovani                       |
| 179 | The Customized Battery testing bench and selection process adopted for satellite Applications                                          | Aissa Boutte*                                                                                                |
| 180 | Experimental Measurements of Shielding Influences on Near Magnetic Field for LED Lighting Sources                                      | Abdelhakim Zeghoudi; Laurent Canale*; Abdelber Bendaoud; Amar Tilmatine; Georges Zissis                      |
| 182 | Voltage Amplitude Measurement Techniques for Power System Protection and Control Applications                                          | Farnam Hojatpanah; Firouz Badrkhani Ajaei*                                                                   |
| 183 | Rule-Based Home Energy Management Model for Optimal Load Shifting Considering Energy Storage and Distribution System Operator Requests | Ubaid Ur Rehman; Pedro Faria; Luis Gomes; Zita Vale*                                                         |
| 184 | A GAN Data Augmentation approach for trading applications in European Carbon Emission Allowances                                       | Michele Bellomo; Silvia Trimarchi; Alessandro Niccolai*; Marco Lorenzo; Fabio Casamatta; Francesco Grimaccia |
| 187 | PSpice Modeling of Three-Phase Power Controlled Rectifier with Three Case Studies                                                      | Faisal A. Aloufi*; Ibrahim Al-Kadi; Ahmad Albin Hamad                                                        |
| 188 | Enhancing Solar Radiation Forecasting with Hybrid Ensemble Empirical Mode Decomposition and Machine Learning Techniques                | Ahmed Aghmadi; Osama Mohammed*                                                                               |
| 189 | Characterization of Bifacial Photovoltaic Modules Based on I-V Curves Outdoor Measurement                                              | Alberto Dolara; Sonia Leva; Domenico Mazzeo*; Emanuele Giovanni Ogliari                                      |
| 190 | Fuzzy Logic based MPPT Control Strategies of PV Systems                                                                                | Jamel Riahi; Hamza Nasri; Silvano Vergura*; Hichem Taghouti                                                  |

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|-----|-------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| 194 | Optimal Management of Microgrid Under PV Forecast Uncertainty Using Stochastic Programming                                                                  | Valentin Mathieu*; Gregoire Pichenot; Quoc Tuan Tran                                                                                                |
| 195 | Hourly Electricity Price Prediction Applying Deep Learning for Electricity Market Management                                                                | Ibrahim Mohamed Gaber; Rania A Ibrahim*                                                                                                             |
| 196 | Photovoltaic Plant State-of-Health estimation by means of UAV and Electric Measurements                                                                     | Alberto Dolara*; Alessandro Niccolai; Francesco Grimaccia                                                                                           |
| 198 | A priority-ordered incentive-based smart charging strategy of electric vehicles to determine the optimal size of solar power plant at the charging stations | Pratik Harsh*; Debapriya Prof. Das                                                                                                                  |
| 199 | Servitization for Ecological Sustainability                                                                                                                 | V.T. Rakesh*; Preetha Menon; Ramakrishnan Raman                                                                                                     |
| 200 | Workers' motor efficiency assessment through an IMU-based standardized test and an automated and error-minimizing measurement procedure                     | Tommaso Di Libero*; Chiara Carissimo; Gianni Cerro; Luigi Fattorini; Luigi Ferrigno; Angelo Rodio                                                   |
| 201 | Optimal Design and Cost Analysis of Microgrid Hybrid Renewable Energy Systems with Hydrogen Production and Storage and Battery                              | Wahiba Yaici*; Evgueniy Entchev; Andres Annuck; Michela Longo                                                                                       |
| 202 | Quasi-Z-Source Cascaded H-Bridge Multilevel Inverters for PV Applications with Fault                                                                        | David Carrasco-González; Pablo Horrillo-Quintero; Pablo García-Triviño; Raúl Sarrias-Mena; Carlos Andrés García-Vázquez; Luis M. Fernández-Ramírez* |
| 203 | Simulation Analysis of an Interleaved Silicon Carbide (SiC) Full-Bridge Converter                                                                           | Asif Rasul; José Baptista*                                                                                                                          |
| 205 | Inverter Based Resources Integration Through A Bridgeless Boost Converter for DC-Microgrid Applications                                                     | Mahmoud Amin*; Ahmed S Soliman; Fayez El-Sousy; Osama Mohammed                                                                                      |
| 207 | Green Mobility Application in Malaga: Analysis of the Transition from ICE to EV                                                                             | Cristian G Colombo*; Michela Longo; Federica Foadelli; Wahiba Yaici; Maria Garcia Diaz                                                              |
| 212 | Energy storage systems for voltage regulation: Analysis for the railway junction of Rome                                                                    | Alessandro Ruvio*; Marco Maccioni; Gabriele Di Girolamo                                                                                             |
| 213 | An Improved SI-ANPC Grid-Connected Inverter Without Short-Circuit and Circulating-Current Issues                                                            | Xiaobiao Wang*; Huafeng Xiao                                                                                                                        |
| 214 | Analysis of the energy matrix decarbonization in the operation of the large mining power distribution systems: The chilean case                             | Federico Silvestro*; Luis Vaccaro; Luis Moran; Juan Araneda; Francesca Pessino; Jose Espinoza                                                       |
| 215 | Optimization of Audible Noise Levels in an AC/DC Hybrid Transmission Line                                                                                   | Carlos Tejada Martinez*; Fermin P. Espino-Cortes; Rodrigo Nuricumbo Guillén                                                                         |

|     |                                                                                                                                                                          |                                                                                                 |
|-----|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| 217 | Monitoring and Modelling Photovoltaic Soiling in an Urban Environment                                                                                                    | Leonardo Micheli*                                                                               |
| 218 | A Critical Review of Nigerian Electricity Policies between 2001 and 2020                                                                                                 | Justicia Otobo*; Rusdy Hartungii; Abouzar Estebarsari; Yusuf Ibrahim                            |
| 219 | Integrating Risk Assessment into the Optimal Placement and Sizing of Distributed Generation and Capacitor Banks in Power Distribution Networks                           | Oscar Gomez*; Luia Gallego; Carlos Zapata                                                       |
| 220 | Review of the IEEE Standard Related to Emergency Diesel Generators in Nuclear Power Plants                                                                               | Sanghoun Joung*; Seungbeak Park; Hoon Keon Lee                                                  |
| 221 | Correct Initialization of Extended Harmonic Domain -Based Models for Accurate Representation of Frequency Dynamics                                                       | Uriel Vargas*; George Cristian Lazaroiu                                                         |
| 224 | Learning from ChatGPT: A Transformer-Based Model for Wind Power Forecasting                                                                                              | Xiaoran Dai*; Guo-Ping Liu; Wenshan Hu; Zhongcheng Lei; Hong Zhou                               |
| 226 | Forecasting Short-term Fine Particulate Matter Concentration Using an Autoregressive Model                                                                               | Fan Wu*; Yu-Tong Shao; Ziqiao Xu; Kevin Sheng-Kai Ma                                            |
| 227 | Novel optimal energy management with demand response for a real-time community microgrid                                                                                 | Pavitra Sharma*; Debjane Bhattacharjee; Hitesh Datt Mathur; Puneet Mishra; Houria Siguerdidjane |
| 229 | PV Power Production and Consumption Estimation with Uncertainty bounds in Smart Energy Grids                                                                             | Phil Aupke*; Seema Seema; Andreas Kassler; Andreas Theocharis; Dan-Eric Archer                  |
| 231 | Improving Precision and Efficiency at Laser Shooting Ranges: Using Video Processing for Impact Quantification.                                                           | David Rivas*                                                                                    |
| 232 | Preliminary analysis of stand-alone street lighting system with PV and battery: measurements and simulations of a case study                                             | Elisa Belloni*; Andrea Massaccesi; Cristina Moscattiello; Luigi Martirano                       |
| 233 | Hyperband Optimization of Stacked Bidirectional Long Short-Term Memory Neural Network for the State of Charge Estimation                                                 | Panagiotis Eleftheriadis*; Manasa Hedge; Harpreet Singh Sohal; Sonia Leva                       |
| 234 | System for identifying the origin of the shot for the laser shooting range at the Brigada de Fuerzas Especiales N° 9 Patria                                              | Michael D Torres*; Anthony Yáñez; David Rivas; Víctor Bautista                                  |
| 236 | On the Effect of Blade Angle on Lightning Strikes to Wind Turbine Blades: Characteristic Impedance and Electrical Parameters                                             | Omid Homaei*; Mohammad Javad Nasiri; Michał Jasiński; Zbigniew Leonowicz                        |
| 239 | Towards the energy optimization and decarbonization of urban settings: proposal of a strategy at Neighbourhood Level to Foster Nearly Zero and Positive Energy Districts | Laura Cirrincione*; Maria La Gennusa; Giorgia Peri; Gianluca Scaccianoce; Maria Chiara Camarda  |
| 241 | MTPA and flux weakening control of electric motors: a numerical approach                                                                                                 | Elia Grano*; Ettore Bianco; Henrique De Carvalho Pinheiro; Massimiliana Carello                 |

|     |                                                                                                                |                                                                                                            |
|-----|----------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|
| 242 | Work Safety in Shipyard Workshops: an Application to a Case Study                                              | Gianluca Scaccianoce*; Maria La Gennusa; Silvia Pennisi; Daniele Enea; Aurora Bondi                        |
| 243 | Energy, environmental, economic and exergy analysis of different heating systems for a residential building    | Axel Masulli; Alessandro Ciancio*; Laura Pompei; Fabio Nardecchia                                          |
| 244 | Prosumer energy management under controllable power transactions with the grid                                 | Nikolaos S. Kelepouris*; Dimitrios Kelepouris; Aggelos S. Bouhouras; Georgios C. Christoforidis            |
| 245 | Investigation of Controlled Fault Interruption Strategies in Isolated MV Distribution Systems                  | Simone Carni*; Simone Negri; Marco Riva; Roberto Faranda                                                   |
| 246 | Exergy evaluation of a trigeneration plant applied to industry sector: an Italian case study                   | Leonardo Cupaiolo; Matteo Bartolini; Alessandro Ciancio*; Fabio Nardecchia; Laura Pompei                   |
| 247 | Enhance Urban Energy Management and Decarbonization Through an EC-based Approach                               | Laura Cirrincione*; Vasiliki Geropanta; Giorgia Peri; Gianluca Scaccianoce                                 |
| 248 | A statistical analysis of predictive maintenance tests on synthetic ester-filled railway transformers          | Elmer Sorrentino*; Maria Garcia; Domingo Urquiza; Diego García                                             |
| 249 | Reversible Traction Substations in DC Railway Systems: A Comparative Study of Approaches                       | Hamed Jafari Kaleybar*; Morris Brenna; Luca Pugi                                                           |
| 251 | Comparison of Flatness-based Control and Field-Oriented Control for PMSMs in Automotive Water Pump Application | Milad Akrami; Ehsan Jamshidpour*; Vincent Frick; Serge Pierfederici                                        |
| 253 | The sustainable energy development in Southern Italy through green hydrogen: a cost analysis                   | Salvatore Ruffino*; Matteo Coveri; Marco Ferraro; Fabio Massaro; Eleonora Riva Sanseverino                 |
| 255 | The role of a biogas plant to increase the smartness level of a seaside town                                   | Federica Notarfonso; Luigi Dodaro; Gisela Arias; Fabio Nardecchia; Laura Pompei*                           |
| 256 | Reference Voltage Adjustment Strategies for Dynamic Voltage Compensator                                        | Ehsan Kazemi-Robati*; Hossein Hafezi; Roberto Faranda; Bernardo Silva                                      |
| 257 | Smart Cities and Communities: a case study of agrovoltaic systems applied to an Italian urban periphery        | Federico D'Alessandro; Fabrizio Sevagian; Axel Riccardo Massulli; Fabio Nardecchia; Laura Pompei*          |
| 258 | Light pollution on the historical center of Palermo. A case study                                              | Daniele Milone; Miriam Mantegna; Andrea Guericio; Domenico Curto*; Pierluca Martorana; Margherita Frascati |
| 259 | On the CHP Flexibility Expansion in the Power System with High Share of Variable and Nuclear Generation        | Yuseok Lee*; Woo-Jung Kim; Yeong-Han Chun; Hae-Seong Jeong                                                 |
| 260 | Variable Structure Control of a Virtual Synchronous Generator for LVRT in presence of Local Load               | Salil M Dubey*; Zakir H Rather; Suryanarayana Doolla                                                       |
| 261 | Residential Renewable Energy Community: a Techno-Economic Analysis of the Italian Approach                     | Grazia Barchi*; Marco Pierro; Mattia Secchi; David Moser                                                   |

|     |                                                                                                                                                          |                                                                                                                       |
|-----|----------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|
| 262 | A GIS-based Approach for Optimal Electric Vehicles Charging Stations Deployment                                                                          | Alessandro Niccolai*; Babak Ranjgar; Silvia Trimarchi                                                                 |
| 263 | Hardware-in-the-Loop and Traffic-in-the-Loop for Testing Cooperative Intersection Management                                                             | Facundo Storani*; Roberta Di Pace; Stefano De Luca                                                                    |
| 264 | Energy Management System for Energy-Intensive Radiology Appliances                                                                                       | Abbas Javadi; Ali Esmaeel Nezhad*; Pedro H.J.Nardelli; Subham Sahoo                                                   |
| 265 | Adapting ENTSO-E network data for power system simulation                                                                                                | Pablo Ledesma*; Francisco Arredondo ; María Angeles Moreno                                                            |
| 268 | Modeling and Analysis of Electrical Circuit Connections in the Piezoelectric Cantilever Array for Vibration Energy Harvester                             | Li Wah Thong*; Kok Swee Leong; Roszaidi Ramlan                                                                        |
| 269 | Reinforcement Learning based Energy Management System for Grid-Connected PV plants and EnergyStored Quasi-Z-source Cascaded H-Bridge Multilevel Inverter | Ehsan Hosseini; Pablo García-Triviño; Raúl Sarrías-Mena; Carlos Andrés García-Vázquez; Luis M. Fernández-Ramírez*     |
| 270 | Harmonic Propagation in Hybrid Microgrids: A Simulation-based Analysis                                                                                   | Christian R Jiménez-Román*; Francisco Arredondo ; Daniel Serrano-Jiménez; Emmanuel Hernández-Mayoral                  |
| 271 | Ex-ante analysis and baseline estimation for pilot sites using machine and deep learning                                                                 | Dimitrios Thomas; Antonio De Paola*; Evangelos Kotsakis; Nikoleta Andreadou; Gianluca Fulli                           |
| 272 | Use of Piecewise Linear Regression to Model and Analyze EV Charging Curve                                                                                | Daniele Martini; Alessandro Saldarini; Michela Longo*; Morris Brenna; Federito Vitti; Andrea Maserti; Fabio Filorusso |
| 273 | A LEAP Energy Model of the Philippines' Luzon Grid: Assessment of the Effects of Low-Carbon Policies in Generation Expansion                             | Luigi S. Teola*; Adonis Emmanuel Tio; Michael Angelo Pedrasa                                                          |
| 275 | Automatic Generation Control via Hydrogen Storage Power Plants in a Nodal Voltage Angle Controlled Grid                                                  | Nayeemuddin Ahmed*; Harald Weber                                                                                      |
| 276 | Degradation Assessment for Prototypal Perovskite Photovoltaic Modules in Long Term Outdoor Experimental Campaign                                         | Gabriele Malgaroli*; Giona Aime; Alessandro Ciocia; Stéphanie Narbey; Luca Saglietti; Filippo Spertino                |
| 277 | Modelling of a Free-Piston Generator Based on Spark-Ignition Engine, Linear Electric Machine and Active Rectifier                                        | Alberto Dolara*; Giovanni Gaetano Gianetti; Sonia Leva; Tommaso Lucchini; Andrea Facheris; Francesco Fasana           |
| 278 | The Adoption of the HD-ERTMS for Improving the Capacity of Single-Track Railway Lines                                                                    | Luca D'acerno*; Michele Napolitano; Luca De Matteis; Mario D'avino; Sebastiano D'avanzo; Marilisa Botte               |
| 279 | Proposal of an Energy Efficient LED LMM Class AB Driver with Bias-T Capable of VLC IEEE 802.15.7                                                         | Gabriel D Colvero*; Marco A Dalla Costa; Lucas Teixeira; Felipe Loose; Vitor Padoin                                   |

|     |                                                                                                                                         |                                                                                                                              |
|-----|-----------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
| 280 | Risk Cost Analysis of Fuel Dependency in a Sustainable Energy Transition by Replacing HSD with LNG: A Case Study of Lombok Power System | Sarjiya Sarjiya; Tumiran Tom Tumiran; Lesnanto Multa Putranto; Rizki Firmansyah Setya Budi; Ahmad A Muthahhari*; Ira Savitri |
| 282 | SVSC Controlled Motion Sensor Free Solar Powered BLDCM Drive                                                                            | Aryadip Sen*; Bhim Singh                                                                                                     |
| 283 | Parameter Estimation of a Lithium-ion Battery Equivalent Circuit Model Using a Pseudo-random Impulse Sequence Perturbation              | Zandile C Moyo*; Fredrick M Mwaniki                                                                                          |
| 284 | Characterization of a commercial Nickel-Rich/Silicon-Graphite battery, under long term static and dynamic cycling                       | Jorge Alonso Del Valle*; Manuela González; Juan Carlos Viera; Enrique E. Valdés; Dailenis Castro; David Anseán               |
| 285 | Analysis problematics of transformer noise in distribution room in office building                                                      | Miroslav Gutten*; Daniel Korenciak; Martin Karman                                                                            |
| 286 | An Overview of Data-Driven Methods for the State of Health Estimation                                                                   | Panagiotis Eleftheriadis*; Spyridon Giazitzis; Cemay Ozmalatyalilar; Sonia Leva; Riccardo Zich                               |
| 287 | Towards smart communities: evaluation of solar photovoltaic panels on a parking depot                                                   | Flavia Vespasiano; Domiziana Vespasiano; Celestino Troiani; Fabio Nardecchia; Laura Pompei*                                  |
| 288 | Investigating the Capability of a Power Converter in Delivering Net Carbon Reduction: Presentation of the First LCA Approach            | Kama'an J Geoffrey*; Stefano Bennati; Pericle Zanchetta ; Norma Anglani                                                      |
| 290 | Maximizing PV Hosting Capacity in Unbalanced Distribution Systems with High EVs Penetration                                             | Jairo Gonzalo Yumbla Romero*; Juan Home; Tiago Pinto; Jose R Sanches Mantovani                                               |
| 291 | A New Hybrid Forecasting Model for Solar Energy Output                                                                                  | Oveis Abedinia*; Behrouz Sobhani; Mehdi Bagheri                                                                              |
| 292 | Experimental test of the thermal performance of a nanotechnology material for energy efficient building applications                    | Giacomo Salvadori*; Michele Rocca; Francesco Leccese; Fabio Fantozzi                                                         |
| 293 | Scaled Design & Fast Prototyping of Fixed Wing Drone with VTOL Capabilities                                                             | Luca Pugi*; Lorenzo Berzi; Cosimo Picchi; Bernardo Incerpi; Giuseppe Mattei; Lorenzo Franchi                                 |
| 294 | A Novel Solution Technique for the Expansion Planning of Modern Distribution Systems                                                    | Jonathan P. Ayala Marcelo*; Gregorio Muñoz-Delgado; Javier Contreras; Jose R Sanches Mantovani                               |
| 296 | Lightning Transients in Wind Turbines: A Comparative Study of Two Tower/Blade Models                                                    | Mohammad Javad Nasiri; Omid Homaei*; Ahmad Gholami; Michał Jasiński; Zbigniew Leonowicz                                      |
| 297 | Tuning of grid-forming converters with a settings-free optimization algorithm to improve frequency response of low-inertia systems      | Miguel Ramirez-Gonzalez*; Felix Rafael Segundo Sevilla; Petr Korba                                                           |
| 298 | A scenario-based battery storage optimization method for diverse P2P energy trading                                                     | Yasuhiro Takeda*; Kenji Tanaka                                                                                               |

|     |                                                                                                                                                                |                                                                                                                                               |
|-----|----------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| 299 | A novel parameters identification method of Lithium-ion battery equivalent circuit model under dynamic stress test                                             | Hung-Yu Pai; Yi-Hua Liu; Guan-Jhu Chen; Desire D. Rasolomampionona; Elia Brescia; Enrico De Tuglie*                                           |
| 300 | The Influence of Renewable Energy Source Penetration on Load Frequency Control                                                                                 | Wiktor Wroblewski; Desire D. Rasolomampionona; Mariusz Klos; Hung-Yu Pai; Pasquale Montegiglio*; Enrico De Tuglie                             |
| 301 | Analysis of correlations between electric arc furnace model coefficients                                                                                       | Maciej Klimas*; Dariusz Grabowski                                                                                                             |
| 302 | Optimal energy purchasing and balancing services provision of a bus fleet operator                                                                             | Benjamin Blat Belmonte*; Simon Massat; Stephan Rinderknecht                                                                                   |
| 303 | Centralized Operation of Multi-Energy Microgrids                                                                                                               | Ali Esmaeel Nezhad; Mohammad Javadi*; Pedro H.J. Nardelli; Subham Sahoo                                                                       |
| 304 | A Generic Parametric Framework for Peer-to-Peer Electricity Market Design                                                                                      | Ali Mohammad Saghiri*; Somayeh Moazeni                                                                                                        |
| 305 | Comparison Between Permanent Magnet Assisted Synchronous Reluctance Motors Considering Electric Vehicle Driving Cycle                                          | Gianvito Gallicchio*; Francesco Cupertino                                                                                                     |
| 306 | Simulation and Comparison of a Loss Minimization Algorithm with Conventional Efficiency Improvement Methods for Field-Oriented Control of an Induction Machine | Tomáš Lažek*; Ivo Pazdera; Marek Toman                                                                                                        |
| 307 | A Generalized Approach for Evaluating the Operating Efficiency of Multi-Carrier Energy Systems                                                                 | Giulia Amato; Enrico De Tuglie; Angelo Martella; Pasquale Montegiglio*; Desire D. Rasolomampionona; Hung-Yu Pai                               |
| 308 | Deep Learning-Based Optimal Switch Placement in Smart Power Distribution Systems                                                                               | Mohammad Rastegar; Mehrdad Ebrahimi; Kiana Karami*                                                                                            |
| 309 | Analysis of wind energy production offshore in a scenario of extreme drought.                                                                                  | Paulo J. Santos*                                                                                                                              |
| 310 | Detection and Localization of Stealth False Data Injection Attacks in Active Power Distribution Systems Using an Ensemble of Deep CNNs                         | Mohammad Reza Dehbozorgi; Mohammad Rastegar*; Mohammad Reza Arani                                                                             |
| 312 | Decentralized PEV Control Based on a Subgradient Method for Mixed-Integer Programming Problems                                                                 | Simone Barcellona; Alessandro Di Giorgio; Francesco Liberati*                                                                                 |
| 313 | Improved Sliding Mode Control and Active Damping for LCL-filtered Voltage Source Inverter Connected to Distorted Grid                                          | Amir Rabbani; Mohammad Mardaneh; Ehsan Jamshidpour*; Philippe Poure                                                                           |
| 315 | Forecasting Methodologies of the Electrical Load in Urban Distribution Networks: a Case Study in Milan, Italy                                                  | Edoardo Daccò*; Davide Falabretti; Dario Ronzio; Riccardo Lazzari; Daniele Perona; Alessandro Bosisio; Gaetano Iannarelli; Alessandro Cirocco |
| 316 | Profitability of Building Integrated PVs Enhanced by Storage and Load Management                                                                               | Angelos I. Nousedilis*; Nikolaos S. Kelepouris; Aggelos S. Bouhouras; Georgios C. Christoforidis                                              |

|     |                                                                                                                                        |                                                                                                                                               |
|-----|----------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| 317 | Distributed Cooperative Secondary Control for Critical Bus Voltage Regulation                                                          | Nada Mosaad Elashmoni*; Omar Abdel-Rahim; tamer F. Megahed; Tanemasa Asano; Sobhy M. Abdelkader                                               |
| 318 | Home Load Disaggregation using Deep Learning and Bayesian Optimization: A Case Study in Arctic Climate in Northern Norway              | Nasrin Kianpoor*; Bjarte Hoff; Tond Østrem                                                                                                    |
| 320 | Effect of the Minimum Bid Size on the Wholesale Markets                                                                                | Simone Minniti; An Nguyen*; Trung Tran; Quan Tran; P.H. Nguyen                                                                                |
| 321 | Experimental Study and Comparison of Switching Loss Behavior of Si IGBT and SiC MOSFET in Dual Active Bridge Series Resonant Converter | Onkar G Bhakare*; Kousik Ghosh; Surja Sekhar Chakraborty; Kamalesh Hatua                                                                      |
| 322 | Design of a Low-Voltage Mock-Up of a New Multi-Terminal Italian HVDC Transmission System                                               | Francesca Pizzimenti*; Stefano Lauria; Fabio Giulii Capponi; Luca Buono; Francesco Palone; Roberto Spezie; Gabriele Tresso; Pierluigi Vacante |
| 323 | Large-Signal Average Modeling of Two Decentralized Distributed Generations Based on Boost Converter                                    | Roghayeh Gavagsaz-Ghoachani; Matheepot Phattanasak; Mohammad Afkar; Ehsan Jamshidpour*; Serge Pierfederici                                    |
| 324 | Performance analysis of satellite navigation systems in urban and rural areas of the Andean region of Ecuador: A field study           | David Rivas*                                                                                                                                  |
| 325 | Design of a Reduced Scale Prototype for a SiC-based HVDC Hybrid Circuit Breaker for the New Italian HVDC Network                       | Francesca Pizzimenti*; Stefano Lauria; Fabio Giulii Capponi; Luca Buono; Francesco Palone; Lorenzo Papi; Roberto Spezie; Pierluigi Vacante    |
| 327 | Loadability curves for the new Terna's "5F" high capacity overhead lines                                                               | Francesco Palone*; Luca Buono; Stefano Lauria; Roberto Spezie; Maria Rosaria Guarniere; Marco Maccioni; Lorenzo Papi                          |
| 328 | Preliminary Sizing and Operation Analysis of the DTT Electrical Network System                                                         | Marzia Caldora; Matteo Manganelli*; Maria Carmen Falvo; Simone Minucci; Alessandro Lampasi; Roberto Romano                                    |
| 329 | Enabling the Seamless Coordination and Synchronization of Microgrids using Batteries                                                   | Diana Patricia Moran-Rio; Javier Roldan-Perez*; Milan Prodanovic; Aurelio García-Cerrada                                                      |
| 330 | Non-Intrusive Load Monitoring (NILM) using Deep Neural Networks: A Review                                                              | Mohammad Irani Azad; Roozbeh Rajabi; Abouzar Estebarsari*                                                                                     |
| 332 | Applicability of hybrid power systems for fishing vessels                                                                              | Marija Koričan*; Nikola Vladimir; Tatjana Haramina; Neven Alujevic; Krešimir Vučković                                                         |
| 333 | A model for estimating the energy demand of the EV charging stations in an urban area                                                  | Alessio Melis; Giuditta Pisano*; Fabrizio Pilo; Simona Ruggeri                                                                                |
| 334 | Real-World Data-Driven Electric Vehicle Charge and Discharge Planning with Deep Q-Network                                              | Kosaku Nakano*; Kenji Tanaka                                                                                                                  |

|     |                                                                                                                                                  |                                                                                                                                      |
|-----|--------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|
| 335 | Sequence-to-Sequence Model with Transformer-based Attention Mechanism and Temporal Pooling for Non-Intrusive Load Monitoring                     | Mohammad Irani Azad; Roozbeh Rajabi; Abouzar Estebarsari*                                                                            |
| 336 | Time-of-Use Tariff with Local Wind Generation                                                                                                    | Abouzar Estebarsari*; Aaron Gillich; Roozbeh Rajabi                                                                                  |
| 337 | Various Aspects of Energy Transition: Technologies, Economy, and Social Synergies to Sustainable Future                                          | Elżbieta Jasińska; Marek Jasinski; Zbigniew Leonowicz; Luigi Martirano; Radomir Gono; Michał Jasiński*                               |
| 340 | PV Advancements & Challenges: Forecasting Techniques, Real Applications, and Grid Integration for a Sustainable Energy Future                    | Michał Jasiński*; Zbigniew Leonowicz; Jan Jasinski; Luigi Martirano; Radomir Gono                                                    |
| 342 | Microgrids in View of Forecasting and Management – Challenges & Opportunities Considering Emerging Technologies Integration                      | Łukasz Jasiński; Jacek Rezmer; Zbigniew Leonowicz; Luigi Martirano; Michał Jasiński*                                                 |
| 344 | Analysis of overhead line rating forecasting in a IEEE-24 bus system network                                                                     | Paula Castillo*; Igor Albizu; M. Terese Bedialauneta; Elvira Fernandez; Patricio Barbecho                                            |
| 346 | FPGA-based Acceleration Of A Neural Network For Symbol Classification With Hardware-Optimised Multiplier Implementations                         | Lakshay Chandna*; Megha Sharma; Kushik Agarwal; Anup Kumar Mandpura; Himanshu Singh                                                  |
| 349 | On the Effect of Partially Interconnected Grounding Systems in Wind Farms on Lightning Transients                                                | Omid Homaei*; Mohammad Javad Nasiri; Michał Jasiński; Zbigniew Leonowicz                                                             |
| 350 | Microgrid Energy Management System with cost minimization                                                                                        | Mina Bekheet*                                                                                                                        |
| 352 | Leather industry and sustainable materials-Cost-Benefit Analysis                                                                                 | Claudia M Dumitra*; Razvan Dobrescu; Georgiana Moiceanu; Corina Dumitrescu; Augustin Semencescu                                      |
| 353 | Static Security Assessment for Smart Microgrids based on unstable working points clustering                                                      | Giulia Amato; Enrico De Tuglie*; Angelo Martella; Pasquale Montegiglio; Desire D. Rasolomampionona; Hung-Yu Pai                      |
| 354 | Broadband radiometers for the assessment of workers' exposure to UV radiation: comparison of measurement results obtained with different devices | Fabio Bisegna; Chiara Burattini; Laura Pompei; Michele Rocca; Francesco Leccese; Giacomo Salvadori*; Massimo Borra; andrea Militello |
| 355 | Application of Consensus Algorithm in Clustering of Distributed Generation Systems for Wide-Area Management and Control                          | Amin Sharafi*; Arash Vahidnia; Mahdi Jalili                                                                                          |
| 357 | Lightning Electromagnetic Fields above Perfectly Conducting Ground: a review                                                                     | Alice La Fata*; Martino Nicora; Daniele Mestriener; Riccardo Aramini; Renato Procopio; Massimo Brignone; Federico Delfino            |
| 358 | Electrospinning of Polysulphone to Fabricate Anion Exchange Membrane for Cost-Effective Water Electrolysis                                       | Somayyeh Rakhshani; Rodolfo Araneo*; Antonio Rinaldi; Alfonso Pozio                                                                  |

|     |                                                                                                                                              |                                                                                                                                          |
|-----|----------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| 360 | A Hybrid Multi-model Ensemble Feature Selection and SVR Prediction Approach for Accurate Electric Vehicle Demand Prediction: A US Case Study | Fatemeh Marzbani*; Ahmed Osman; Mohamed Hassan                                                                                           |
| 362 | Assessment of the Indirect Lightning Performance of a Distribution Line                                                                      | Amedeo Andreotti; Nagananthini Ravichandran; Luigi D'Orazio ; Domenico Villacci; Alberto Cerretti; Rodolfo Araneo*; Erika Stracqualursi  |
| 363 | Propagation Characteristics of Inter-sheath and Ground Modes on Subsea Buried Cables                                                         | Gianfranco Di Lorenzo; Erika Stracqualursi*; Rodolfo Araneo; Jose Antonio Marinho Brandao Faria; Amedeo Andreotti; Massimo Marzinotto    |
| 364 | Finite Difference Time Domain Implementation of Leader Development Models for Lightning Studies                                              | Erika Stracqualursi*; Zacharias G Datsios; Rodolfo Araneo; Pantelis Mikropoulos; Thomas Tsovilis                                         |
| 365 | 3D FEM Simulation of Electrospinning Machine for the Study of Full-Scale Electrostatic Field on the Electrohydrodynamic Process              | Gianfranco Di Lorenzo; Erika Stracqualursi; Rodolfo Araneo*; Alfonso Pozio; Antonio Rinaldi; Luis Alexander Hein                         |
| 366 | Renewable Energy Communities for Sustainability: A Case Study in the Metropolitan Area of Rome                                               | Edoardo Antonazzi; Gianfranco Di Lorenzo; Erika Stracqualursi; Rodolfo Araneo*                                                           |
| 367 | Power Electronic Converters Enabling the Power Sharing Solution in LVDC Smart Grids for the new Energy Communities                           | Riccardo Loggia*; Francesca Pizzimenti; Andrea Massaccesi; Alessandro Galasso; Cristina Moscatiello; Alessandro Flamini; Luigi Martirano |
| 369 | Real-Time PLC-Based Control for Microgrid Operations Using SCADA System                                                                      | Mostafa Kermani*; Saram Abbasi; Erfan Shirdare; Luigi Martirano                                                                          |

# Analysis of wind energy production offshore in a scenario of extreme drought.

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**Abstract**— Portugal and Spain share the same electricity market (MIBEL). One of the main objectives of this association is to be able to negotiate energy on the international market with advantages for both countries. At the beginning of 2021, with the adoption of decarbonization targets, Portugal decommissioned all coal-fired thermal units. These deactivations pose some challenges to the transmission system dispatch operator. Portugal has a production based on a strong hydro component and the year 2022 was one of extreme drought. Adding to the drought scenario a simultaneous low production of onshore wind occurred. Recourse to thermal production based on natural gas and import were the only resources currently available. In view of the worldwide supply crisis with high natural gas prices, the price of energy has risen sharply and energy import has power limits that cannot be exceeded. This paper aims to create a scenario of future generation needs based on offshore wind generation to respond to years of low and very low hydropower production.

**Keywords**— Off-shore production, System operator, Transmission network, Load diagram, Thermal limit, Power System.

## I. INTRODUCTION.

The energy production in Portugal is based on a strong component of renewable energy. In a scenario of extreme drought, as was the case in 2021 and early 2022, Portugal became very dependent on energy import and thermal production based on natural gas.

The recent energy crisis in 2021 resulted in a "vertiginous" rise in natural gas prices and the consequent impact on thermal generation, putting pressure on electricity prices in wholesale markets. To illustrate these increases, figure 1 shows the evolution of spot prices of electricity in the main European markets [1].

In the wholesale markets, electricity prices in the 2021 crisis are much higher than in the 2008 crisis. The average price in September 2021 in Portugal was 156 €/MWh, while the average price of the worse month in 2008 was no more

than 76 €/MWh.

This growth in wholesale prices occurred in most of the European electricity markets (Fig.1).

European electricity markets [€/MWh]

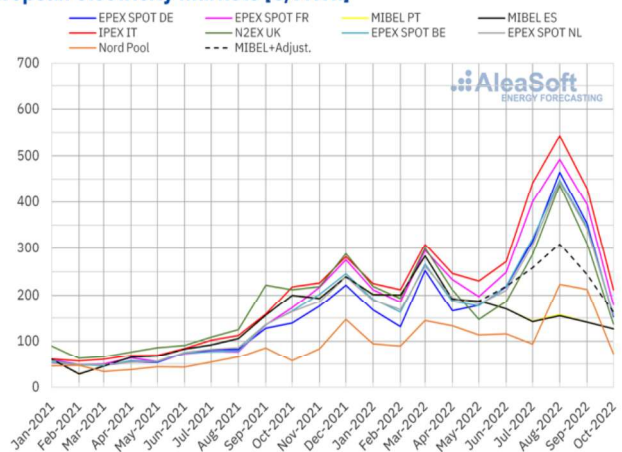


Fig.1- Evolution of the average monthly electricity price in the main European markets [1].

Also in Figure 1, the influence of the "price adjustment" through the Iberian mechanism of decoupling the price of gas from the price of electricity to Natural Gas producers, imposed by the governments of Portugal and Spain [2], is represented by dashes. This mechanism imposes a cap on the price of energy, with a direct reduction in the price of MWh for the year 2022.

The year 2022 was a year of drought for the Iberian Peninsula, particularly in mainland Portugal. As a consequence of the unavailability of hydro and the deactivation of coal-based thermal units during the year 2021 [3], there was an increase in thermal production using natural gas, as well as energy import, with the interconnections reaching the maximum value agreed between the two

countries.

Analyzing the energy exchanges between Portugal and Spain (MIBEL) and between Spain and France (EPEX-FR), it can be seen that Spain, even in a drought year, was an exporter of electricity (fig. 2) [4].

Negative values indicate an energy export balance from Spain to the other countries.

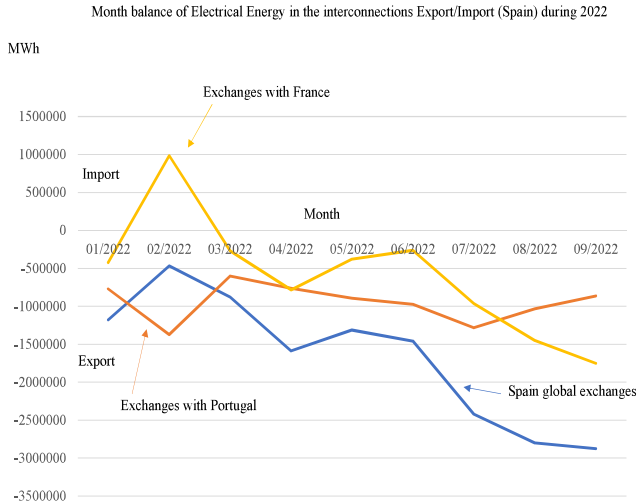


Fig.2. Cross-border exchange balance with Spain (MWh).

Figure 3 shows the evolution of average annual exports between 2013 and 2021 among Spain, Portugal, and France, as well as the average annual values of the spot market (MIBEL e EPEX-FR).

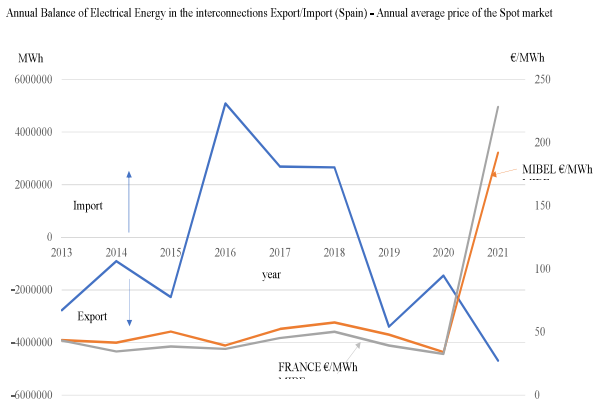


Fig.3. Global exchanges from Spain between 2013 and 2021 balance with Spain (MWh).

The exportation from Spain to the French market occurred following the French nuclear crisis [5] (Fig.4). Namely the low cooling capacity of the units due to the increase in river temperatures and maintenance work of the units [6,7]. Figure 4 shows a clear decrease in nuclear-based production, despite this technology being the one with the largest percentage of production for consumption in France [8].

This decrease in production using nuclear technology together with the energy crisis led to an increase in the average price of energy in the spot market (Fig.4).

The major production of energy in France is nuclear (Fig.4). During 2021 there was a decrease in this type of

production, however, in view of the gas supply crisis, this energy transition process is somewhat "suspended", leading to a demand for nuclear solutions, particularly with the approach of winter and the consequent increase in energy demand. [7].

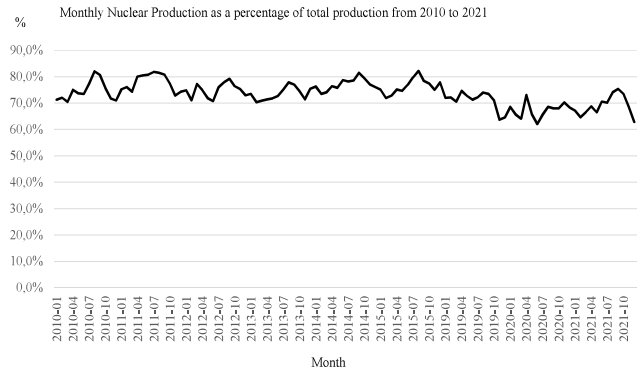


Fig.4. Percentage of nuclear production in France from 2010 to 2021[7].

Thus, in 2021, Spain was an energy exporter in a global overview. The average value involved in these transactions reached practically 900.6 M€ during 2021 excluding exports between Morocco and Andorra which, given the size of the market, are residual [8].

This paper aims to analyze how offshore wind production can contribute to the need of consumption in a scenario of extreme drought.

## II. INSTALLED POWER BY TECHNOLOGY- LOAD PEAK DIAGRAM.

As a result of decarbonization, the Iberian Peninsula decided the deactivation of coal-based thermal units. Portugal completed this goal in 2021, Spain has not yet concluded this reconversion process.

The installed power in Spain and Portugal in renewable resources is 66% of the total installed power of the system (Fig.5) [3, 4]. The production with natural gas is not included in the renewable production.

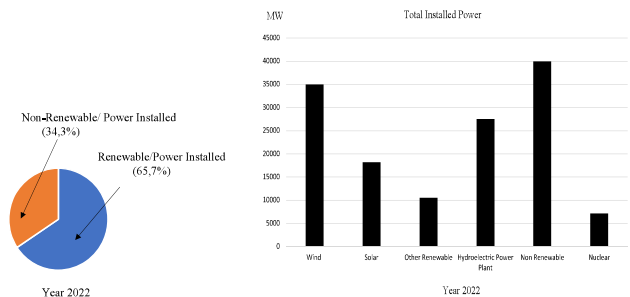


Fig.5. Total installed capacity by technology year 2022 - MIBEL.

There is a strong commitment by governments with the renewable component in the Iberian Peninsula. The trend will be for the renewable component to increase significantly in the coming decades.

Analyzing the Portuguese case, the overall installed power reaches almost 50% of the installed power (Fig. 6), which gives the system a very high safety level under normal operating situations.

However, this level of installed power may not be so relevant depending on the level of penetration of renewable energies, namely the hydro and wind components, which certainly adds some unpredictability in the case of wind power and in years of drought when the hydro production may be compromised.

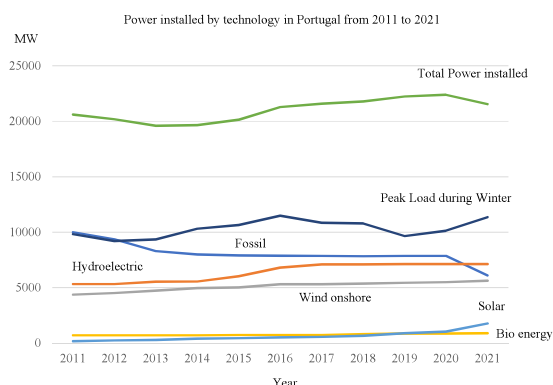


Fig. 6. Total installed capacity in mainland Portugal between 2011 and 2021.

Analyzing the energy production along the period from 2018 to 2022 (Fig. 7) we see that in Portugal the energy based on coal production was abolished in 2021, having an increase in photovoltaic production. The energy based on wind onshore production is stabilized as well as the potential of hydro production. It remains, for Portugal, to explore the offshore side of wind generation.

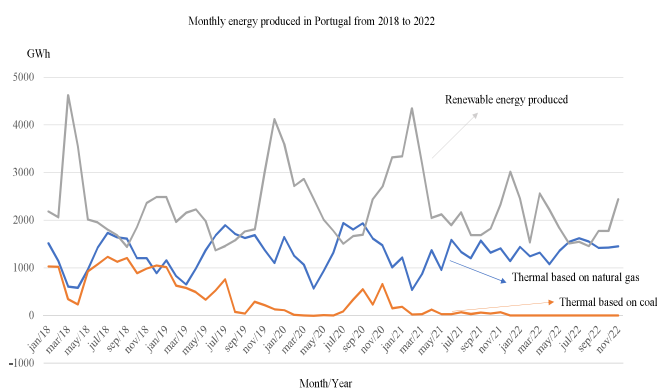


Fig. 7. Energy produced in Portugal between 2018 and 2022.

During the year 2022, an extreme drought situation was experienced. The hydroelectric production in Portugal decreased drastically (Fig. 8), simultaneously with a decrease in wind power production, also unexpectedly, which had repercussions on the way the natural gas-based production had to be used.

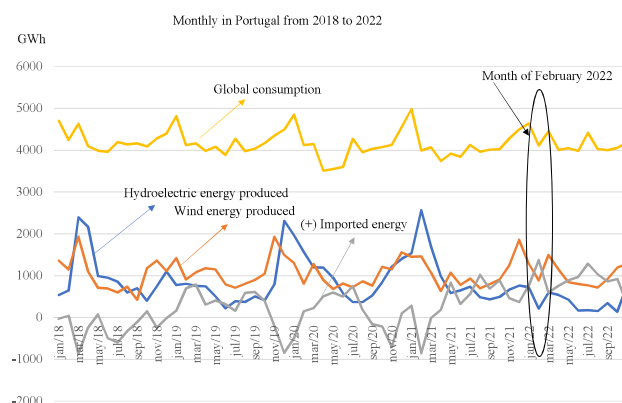


Fig. 8. Energy produced and global consumption in Portugal in 2022.

Moreover, a drought year such as 2022 associated with low wind production implied an increase in imported energy. As can be seen in Fig. 8, energy imports in February reached the highest recorded in the period between 2018 and 2022. This import value, by itself, was not a problem, however in this month, as we will analyze in the next chapter, Portugal was at the limit of the maximum instantaneous power allowed in the interconnections, which could present problems for the network operator if there were interruptions in the network [9].

After analyzing the corresponding months based on wet weather stations, we concluded that the production based on renewable suffered a sharp decrease in February 2022. It was estimated that the deficit in monthly hydroelectric production (February 2022) was around 15% compared with the same period in the previous year, being estimated at around 2000 GWh.

To add to this value and in view of the drop in wind generation, which was estimated at around 300 GWh, there was a total of 2300 GWh that was "withdrawn" from the production system when compared with a similar period of the previous year.

### III. INTERCONNECTION NETWORK AND INSTANTANEOUS POWER LIMITS.

The Iberian peninsula is interconnected with France and Morocco being the highest power connections with France. It is through the interconnection with France that the interconnections with the European market are established. These are made with voltages of 400kV, 220kV and 130kV, according to Fig. 9.



Fig. 9. Map of interconnections Portugal-Spain-France-Morocco [5].

It is now interesting to analyze the interconnections between Portugal and Spain (left side of the figure 9). The Portuguese electricity system is connected to the Spanish electricity system through 10 transmission lines, one of which is the lowest voltage line (the only one at 130 kV) being normally disconnected (Table 1). In addition to the maximum power values, the power operators establish an instantaneous power ceiling for each calendar year. For the year 2022 it was established 5000 MVA (Fig. 10) [9].

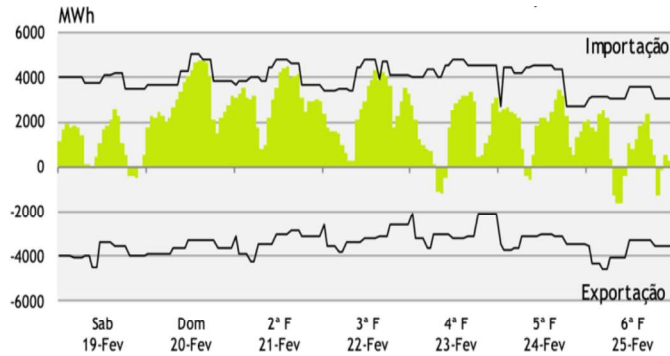


Fig. 10. Values of Instantaneous Power recorded in the interconnections between Portugal and Spain between 19 and 25 February 2022 [8].

In figure 10 it can also be seen that during the month of February this maximum was practically reached between 20 and 22 February 2022. Bearing in mind the thermal limit of the interconnections (Table 1), in the eventuality of an unexpected disconnection, the transmission network operator could experience a conditioned situation [9].

#### IV. OFF-SHORE WIND POTENTIAL DAILY ENERGY PRODUCTION ESTIMATE

Portugal has an oceanic coast with a very favorable wind potential as the winds can reach an annual average of more than  $8\text{ms}^{-1}$ . However the exploitation in deep waters raises the costs and the technological constraints associated. Nevertheless, for relatively short distances from the coast, less than 30km, it is possible to establish an HVAC connection [10], thus reducing the interconnection costs.

Table 1 - Maximum power values at interconnection points

| Voltage | Interconnection #1 (MVA) |        | Interconnection #2 (MVA) |        | Interconnection #3 (MVA) |        |
|---------|--------------------------|--------|--------------------------|--------|--------------------------|--------|
|         | Alto Lindoso- Cartelle 1 |        | Alto Lindoso- Cartelle 2 |        | Lagoaça-Aldeavilla       |        |
|         | Summer                   | Winter | Summer                   | Winter | Summer                   | Winter |
| 400 kV  | 1499                     | 1706   | 1499                     | 1706   | 1469                     | 1706   |
| Voltage | Interconnection #4 (MVA) |        | Interconnection #5 (MVA) |        | Interconnection #6 (MVA) |        |
|         | Falagueira-Cedillo *     |        | Alqueva-Broalves *       |        | Tavira-Guzmán *          |        |
|         | Summer                   | Winter | Summer                   | Winter | Summer                   | Winter |
| 400 kV  | 1386                     | 1386   | 1280                     | 1386   | 1386                     | 1386   |

\*Whit limitations

| Voltage | Interconnection #7 (MVA) |        | Interconnection #8 (MVA) |        | Interconnection #9 (MVA) |        |
|---------|--------------------------|--------|--------------------------|--------|--------------------------|--------|
|         | Pocinho- Aldeavilla1     |        | Pocinho- Aldeavilla2     |        | Pocinho-Saucelle         |        |
|         | Summer                   | Winter | Summer                   | Winter | Summer                   | Winter |
| 220 kV  | 374                      | 435    | 374                      | 435    | 360                      | 430    |

| Voltage | Interconnection #10(MVA) |        |
|---------|--------------------------|--------|
|         | Lindoso-Conchas **       |        |
|         | Summer                   | Winter |
| 130 kV  | 90                       | 131    |

\*\* Normally Open

Portugal has reached its onshore wind potential and thus the possible solutions to reinforce the installed capacity go through reinforcing the power of the current farms and, more interesting, the already exploitation of off-shore wind potential in deep waters. Portugal already has two projects: a European pioneer project (Windfloat) with 2MW of installed power at Viana do Castelo [11]. A second project, located also at the same site, increased to 25MW the installed power [12].

With energy costs rising, the economic viability of deep-water wind farms is very positive. In the case of Portugal, the bathymetric depth off Viana do Castelo is 100m deep at a relatively short distance from land <30km. The good prospects with the first project is to be seen as a possibility for the exploitation of this resource.

With this paper we intend to analyse the solution of an off-shore wind exploitation evaluating its impact in an extreme drought scenario as was the case in February 2022.

Although in the form of a rough estimation it is possible to resort to Wind Atlas [13] so that, in a simplified way, it is possible to analyze the wind power of the coastal area near Viana do Castelo which is the northern point more favorable to this type of exploitation.

Using this information and for the month of February 2022, a distribution of the mean daily wind speed at a height between 100 and 150m was estimated (Fig.11) [13].

Figure 11 presents the daily offshore wind profiles in two scenarios being a more conservative one. It also presents the comparative scenarios for the offshore and onshore wind, where we note the differences in average speeds, being the offshore scenario of more regular winds and higher average speed. A very enhancing factor is that the speeds throughout the year are in opposition. During the summer the speeds are higher in the offshore situation which alternating between offshore and onshore allows a continuity throughout the year.



Fig. 11. Average daily speed profile considered taking into account the wind profile.

This daily profile undergoes changes depending on the season of the year, being the most favorable period the summer, due to the heating of the Iberian Peninsula favoring the maritime wind in this season of the year.

Thus, it was possible to estimate the average wind speed profile for an average day in February. In this way it was possible to estimate a daily energy production per turbine.

If we consider one offshore Park with 3 Turbines with a unit turbine power of 7.5MW (ENERCON- E126) [14] (Fig.12), makes a total of 22.5MW of installed power in a park.

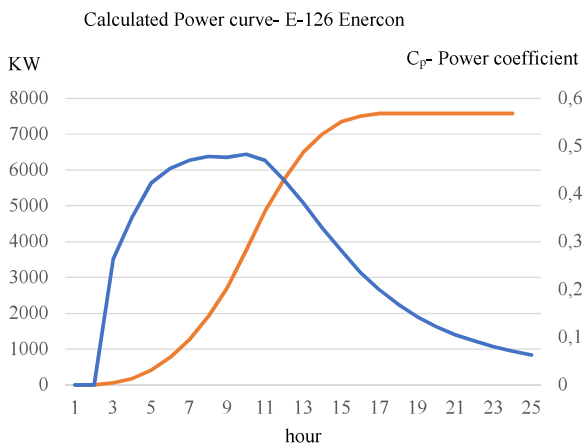


Fig. 11. Characteristic of the wind turbine considered ENERCON E126

The daily production in February, according to the ideal wind conditions, allows reaching a value of about 19 GWh per day (Fig. 12), which makes 532GWh for the month of February in average terms. For three wind turbines production it could reach 1596GWh.

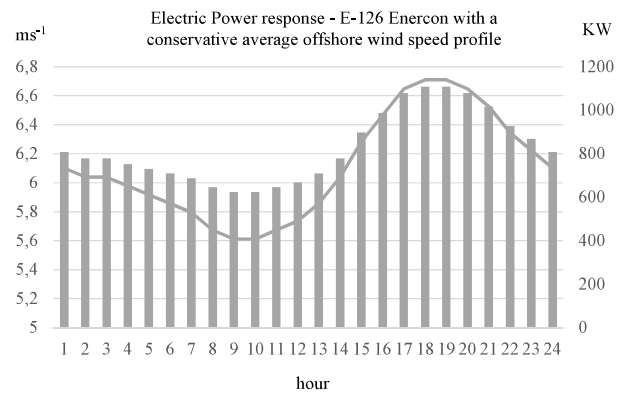


Fig. 12. Electric Power response - E-126 Enercon with a conservative average offshore wind speed profile.

For a scenario where the average offshore winds are higher it is possible to reach a daily production per turbine of 48GWh, which for February and a park with three turbines it is possible to reach about 4032GWh.

The conservative scenario of this production applied to the month of February 2022, where a critical supply scenario existed, would allow the pressure on imports and on natural gas production to be relieved. In Figure 13 this simulation and its impact are simply schematized.

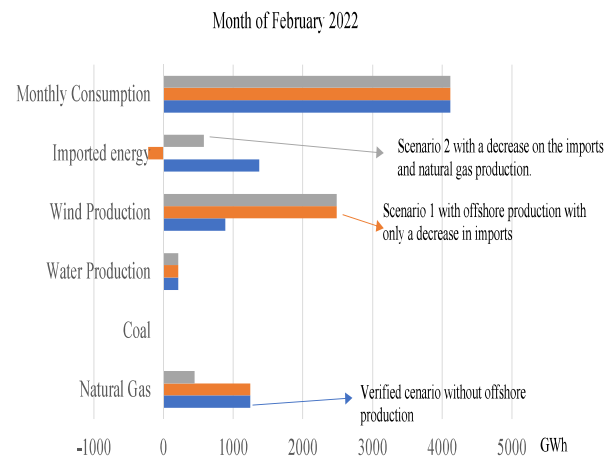


Fig. 13. Production conservative scenario with the introduction of offshore wind generation.

In the following chapter, a brief economic evaluation of the potential investment in the construction of this type of infrastructure will be carried out.

## V. BRIEF ECONOMIC EVALUATION OF THE INVESTMENT

To understand the sustainability and economic viability in the construction of the off-shore wind farm, different criteria can be used based on budgets for the investment project at stake, the end of its life and the time that it takes to recover the original investment. Whether through the Net Present Value (NPV), the Internal Rate of Return (IRR), the Profitability Index (PI), or the Payback Period (PB), the common denominator consists of confronting the amount of capital invested with the operating cash-flows arising during

the project period [14].

Costs calculation usually assumes the prediction of two types of costs that vary depending on the distance of the park from the coast and the water depth considered: investment costs and operation and maintenance costs [15].

Regarding the return on capital investment, by taking into account the two predicted production scenarios and assuming that the energy price in force in February 2022 was around 250€/MWh, makes a daily revenue ranging from EUR 14.25 million to EUR 36 million for a park with three turbines. It is therefore concluded that for this off-shore wind project to be viable, the estimated costs should be such as to enable a positive NPV, a PI greater than 1 or a PB less than the lifetime of the project.

## VI. CONCLUSIONS

The recent energy crisis associated with a year of extreme drought poses several questions to the production system like the Portuguese, which is highly dependent on renewable energies. Energy prices reached record values, due to the increase in natural gas prices as a result of the current instability of the spot markets. In addition, Portugal made a clear bet when removed from its production mix all production based on coal. Thus, in a critical situation of extreme drought, it has direct consequences on the power installed in the Portuguese system, which may lead to stress situations, namely when the import power limit is reached. It remains for Portugal to exploit offshore wind farms. The Atlantic coast is very favorable in terms of wind potential. However, the disadvantages of deep water pose technological challenges associated with this type of exploration at very high cost. However, with the current price of energy in the spot market, this type of exploration is becoming viable. In this paper we tried to show through a simple simulation that this type of offshore wind exploitation would contribute to the resolution of problems of production shortages in extreme drought scenarios.

## ACKNOWLEDGMENT

This work also has been partially supported by the Portuguese Foundation for Science and Technology under project grant[s] UIDB/00308/2020, UIDB/00066/2020 and UIDB/50021/2020, and Instituto Politécnico de Setúbal.

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