R&D NESTER

CREATING A SMART ENERGY FUTURE

10 YEARS

OF RESEARCH AND INNOVATION

PUBLICATIONS

FOR A SMART ENERGY FUTURE

FOREWORD – Creating a Smart Energy Future

The mounting concerns with climate change, security of supply and affordability of energy have brought the traditional energy trilemma to the forefront of the societal discussions. Indeed, such concerns, coupled with the fact that energy transformation is a major source of greenhouse gas emissions, have stimulated the rethinking on the way secondary energy is produced, transported, distributed and consumed, and led to the so-called energy transition. This energy transition is mainly characterized by a fast-changing energy generation mix transformation from few large centralized thermal and hydro power plants towards multiple smaller distributed ones fueled by renewable resources. With power generation becoming possible at multiple downstream locations, this transition is also accompanied by an increasingly shift from a traditional unidirectional flow of energy from central generation to distributed consumption towards a novel bidirectional energy flow at different network levels. This led to the emergence of the so-called producer-consumers, or prosumers, and of an increased consciousness regarding consumption and generation profiles by such prosumers. This also simulated the development of concepts such as energy communities, virtual power plants and microgrids, whereby a mix of generation assets and consumption loads cooperate towards and efficient and effective management of a geographically or logically restricted system, allowing even in some cases an islanded mode of operation detached from the main system.

The variability of the power produced by a large number of the distributed renewable energy sources, such as the wind and the sun, has several implications in the energy system. Concerning the dynamic operation, it requires flexibility from the consumption's side to accommodate the fluctuations on generation and to maintain stability in a system that is currently mostly designed to operate at a

certain system frequency in alternate current. A first level of flexibility is normally provided by the rotating masses of large thermal power plants and their associated inertia, adjusting to any minor mismatched in the balance between generation and consumption. However, such inertia is disappearing with the energy-mix transition mentioned above. This has led to the development and emergence of additional flexibility sources in the system, being it on the load/consumption's side, with the consumer becoming an active player in the system, on the generation's side or in the energy infrastructure itself.

In this context of flexibility needs, energy storage became a relevant element in the energy transition behaving as a buffer between generation and consumption, and providing additional support for occurring mismatches or unbalances, being it on the short-term or the longer-term. Flexibility is also being achieved through transformation of energy from one energy carrier to another, being it electricity, natural gas, hydrogen or any other, in a cross-sectoral perspective calling for a holistic approach to planning and operation. With the purpose of also decarbonizing the mobility sector, where fossil fuels are extensively used, the development of electric vehicles intensified, therefore providing a linkage between the electricity sector and the mobility sector. Similar movements occur in the area of heating and cooling, where electrification is increasing due to the easier decarbonization of the electricity sector. Electrification is thus being used as a means to bring decarbonization to other sectors.

What started with distributed renewable energy sources increasingly became a mesh of a multiplicity of distributed energy resources (DER) where distributed generation coexists with flexible loads, energy storage, electric vehicles, active prosumers, among other elements. Besides the technological complexity associated, there is a need also to ensure that the right regulatory and market mechanisms are in place to ensure a valuable and efficient development, avoid market distortions and establish a level playing field under upgraded maker models. The sheer increase in the number of DER poses challenges to the grid operators in terms of reverse power flows, voltage fluctuations and congestion management, besides the mentioned

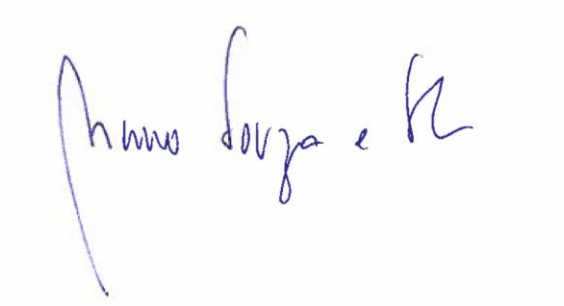
balancing issue. Furthermore, many of these DER, such as solar panels and storage, operate on direct current (DC) and require inverters to interface with the electricity grid. This increases the amount of inverter-based resources and electronics in the system, while decreasing the number of large synchronous elements. Together with the DC devices existing in the residential and commercial domain, this situation is giving rise to the development of low-voltage (LV) and medium-voltage (MV) DC networks. Furthermore, given the increased voltage levels needed in certain situations and the large distance to cover with transmission lines, high voltage direct current (HVDC) lines are becoming more frequent. All this impacts the grid stability and requires an upgraded cooperation between transmission system operators and distribution system operators, as they pursue an optimal management of the sub-systems under their responsibility and the overall efficiency and effectiveness requested by regulators.

The planning and operation of such an increasingly complex system requires proper communication mechanisms and reliable data. The deployment of multiple sensors, smart meters, measurement units (such as PMUs – phasor measurement units) and distributed computing capabilities throughout this complex system, evolving towards a framework of Internet of Things (IoT), allows the collection of a very large amount of data, from distant locations in an almost real-time manner. This contributes to having a more continuous and precise observability of the system, and providing control centers with improved response mechanisms. Additionally, proper methodologies to process such big data can then feed into artificial intelligence, in general, and machine learning, in particular, techniques and algorithms through which valuable insights are extracted and critical decision-making support is obtained. This finds application in areas such as forecasting of behavior of renewable energy sources, forecasting of performance of different devices and components for asset management purposes, computer-vision-aided processes, strategies for energy markets participation, network contingency analysis and scenarios simulation, or optimization and automation of processes, in an ever- growing field of analytics for energy systems.

Such developments are a subset of the ongoing digitalization of the energy system, where digital communication protocols among devices and energy system actors, and standards for communication and information sharing are becoming ubiquitous and contributing to the objectives of reliability, cost efficiency and decarbonization. Data availability and digitalization are also stimulating the swift advent of novel digital services and business opportunities at several levels and involving multiple stakeholders, such as network and system operators, storage management entities, industrial, commercial and residential prosumers, electric vehicles charging operators, manufacturers, and IT and software developers. Digital twins of the networks are becoming a valuable tool in managing the system complexity.

If on one side the energy system is becoming more complex, on the other side it is also becoming smarter in the way it is operated and planned, developing in the direction of smarter grids, smarter cities and smarter use of energy.

It is in this context and in these fields that R&D Nester has been working in the last almost ten years, creating a smart energy future!



Nuno de Souza e Silva

Managing Director

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A. FORECASTING RENEWABLE ENERGY GENERATION

One of the key elements of the energy transition that our society is currently undergoing is the reduction of energy production based on CO2-emitting processes. This includes the replacement of power plants fueled, for example, by traditional coal, with energy generators based on renewable energy sources, such as the wind or the sun.

Most of these renewable energy sources have the property that their supply is not guaranteed in a deterministic manner. Therefore, the amount of energy that is produced at a given moment from a wind farm or from a solar power plant is uncertain.

In order to estimate and reduce the uncertainty associated with the energy produced by such generators, forecasting of renewable energy generation is increasingly important as the total amount and the percentage of such energy increases in the energy system and in particular in the electricity system. This is particularly significant in a system where storage of generated electricity is not yet ubiquitous and the operation of the electrical system requires that total generation have to match total consumption in an almost instantaneous manner.

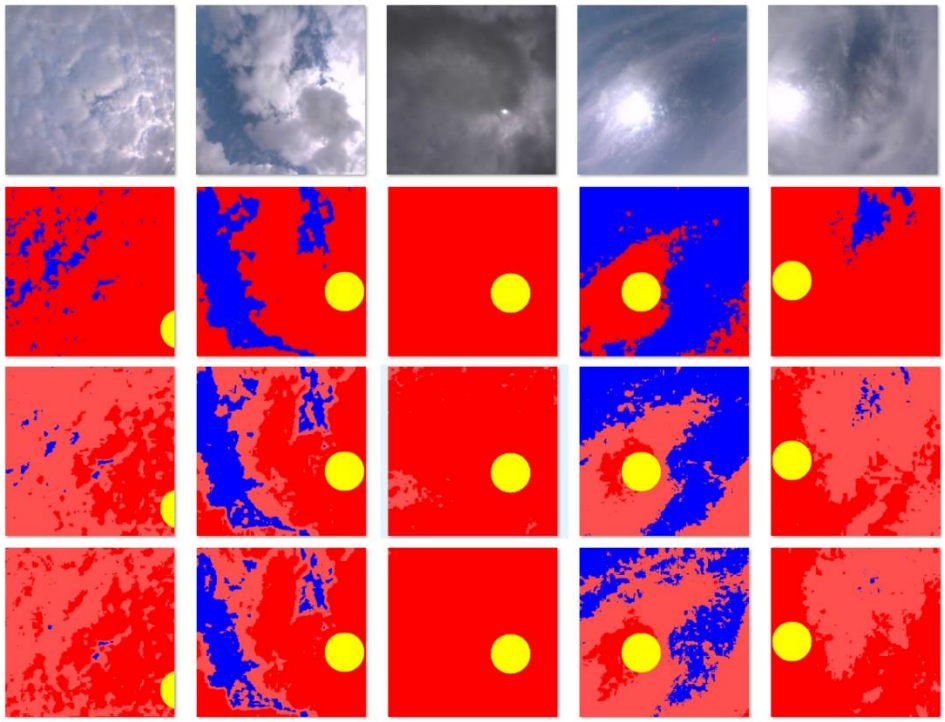
The referred forecasting is therefore important for several entities, such as the system operators and their control rooms that have to maintain the system operating without failures, the power plant owners that have to estimate their revenues, the power plant operators that have to manage their energy offers in organized markets minimizing the risk of penalties from non-delivery, among others.

In our work below, we have addressed wind energy forecasting and solar energy forecasting.

Regarding wind, the use of increasingly sophisticated probabilistic and statistical analysis and algorithms, including neuronal networks, self-

adaptive ensembles, among other techniques, was studied, simulated and tested, as it is becoming a major trend in the field.

On the solar power side, a key aspect is including the clouds' impact in the forecasting process. The use of cloud indexes for that purpose and resorting to information obtained from satellite images and from sky cameras is researched in order to verify and quantify the improvements that can be obtained from using such tools.



Title:	*"Ensemble-Based Estimation Of Wind Power Forecast Uncertainty"*

Published in:	EEM15 – 12th International Conference on the European Energy Market (Lisboa, Portugal, 19-22 May 2015)	
Authors:	Nuno Pinho da Silva, Luís Rosa, Rui Pestana	
Keywords:	forecast uncertainty; operations research; power generation dispatch; power systems management; wind energy integration	

Abstract:	Wind power prediction tools promote secure energy supply with large wind energy integration, which is foundational for achieving a low-carbon economy. While deterministic forecasts provide a time-series, probabilistic forecasts provide interval predictions, thus enabling the perusal of forecast uncertainty for decision-making. This work presents a new nonparametric statistical approach to model the uncertainty in wind power forecasts. The methodology leverages an ensemble of deterministic forecasts using order statistics and linear quantile regression, thus providing an efficient distribution-free probabilistic power forecast system, with sample size and coverage error controlled by the required coverage rate. Experiments include daily data from three months and forecast horizons complying with market applications. The performance is evaluated using the reliability/calibration and the sharpness metrics. The results show competitive reliability, with coverage and sharpness characteristics that compare favorably with reference methods.

Title:	*"Wind Power Forecast Uncertainty Using Dynamic Combination Of Predictions"*

Published in:	Periodica Polytechnica Electrical Engineering and Computer Science (VOL. 59 NO. 3 2015)	
Authors:	Nuno Pinho da Silva, Luís Rosa, Wang Zheng, Rui Pestana	
Keywords:	renewable energy integration; system operation; dynamic wind power forecast; forecast uncertainty	

Abstract:	The system operators rely on forecasting tools to promote security of supply in the case of contingent renewable generation upheaval, thus decreasing the chance of counter trading in the intraday markets. This work introduces a self-adaptive ensemble based method providing optimal point predictions under the square loss function constrained over the probability simplex. The output is used to center a new nonparametric probabilistic power forecast that leverages linear interpolation of the order statistics, thus providing forecast uncertainty estimations. The proposed methodology shows competitive reliability, with coverage and sharpness characteristics that compare favourably with reference methods, thus enabling the perusal of forecast uncertainty in operations planning.

Title:	*"Wind Power Forecast Uncertainty Using Dynamic Combination Of Predictions"*

Published in:	DEMSEE'15 - 10th Jubilee International Conference on Deregulated Electricity Market Issues in South Eastern Europe (Budapest, Hungary, 24-25 September 2015)	DEMSEE'15 BUDAPEST, HUNGARY
Authors:	Nuno Pinho da Silva, Luís Rosa, Wang Zheng, Rui Pestana	
Keywords:	renewable energy integration; system operation; dynamic wind power forecast; forecast uncertainty	

Abstract:	The system operators rely on forecasting tools to promote security of supply in the case of contingent renewable generation upheaval, thus decreasing the chance of counter trading in the intraday markets. This work introduces a self-adaptive ensemble based method providing optimal point predictions under the square loss function constrained over the probability simplex. The output is used to centre a new nonparametric probabilistic forecast that leverages linear interpolation of the order statistics, thus providing forecast uncertainty estimations. The proposed methodology shows competitive reliability, with coverage and sharpness characteristics that compare favorably with reference methods, thus enabling the perusal of forecast uncertainty in operations planning.

Title:	*"Forecasting PV/CPV at National Level – Portugal Experience"*

Published in:	7th International Workshop on the Integration of Solar Power into Power (Berlin, Germany, 24 – 25 October 2017)	7th Solar Integration Workshop, Berlin Germany, 24 - 25 October 2017
Published in:	IET Renewable Power Generation Special Issue title as 'IET solar and Wind integration 2017 Special Issue'	IET Journals, The Institution of Engineering and Technology
Authors:	João Esteves, R. Pastor, N. Pinho da Silva, R. Pestana, Zhibao Chen	
Keywords:	solar power forecast; photovoltaic solar power; concentrated photovoltaic solar power	

Abstract:	The solar power installed capacity all over the world is growing and this renewable energy technology is playing an important role to build a clean energy future. The solar forecast is a necessary tool for the transmission system operator in order to maintain the electricity network safety and reliability. This study aims to report the experience of R&D Nester in the solar forecast at national level in Portugal, forecasting for all solar plants connected to the very high voltage (400, 220 and 150 kV) and high voltage (60 kV) networks, providing this information to the Portuguese transmission system operator, REN. A novel approach to calculate cloud index from images from a sky camera is presented.

Title:	*"Improving The Solar Power Forecast Using Cloud Index Algorithms"*

Published in:	Conferência Ibero-Brasileira de Energia (Lisbon, Portugal, 30 May – 01 June 2019)	
Authors:	João Esteves, Rui Pestana, Nuno Pinho da Silva	
Keywords:	solar forecast; sky camera; cloud index	

Abstract:	The energy mix in Portugal has been changing since the introduction of renewable energy sources. The European Union targets to mitigate global warming is decarbonizing the whole energy sector. Portugal renewable energy revolution started with Wind power generation and, nowadays, the Solar power is beginning to grow and it is expectable to assume a considerable share in the future energy mix of Portugal. In R&D Nester, a continuously working forecast tool was developed and implemented in the model chain of REN, Portuguese transmission system operator. This tool takes into account the physical and technical parameters of the solar power plants converting solar radiation to power. In this paper, a new approach is studied using a sky camera. A case study regarding the improvement of the solar forecast of five solar power plants is presented, using cloud index calculated from images of the sky. To set the case study, real power measurements and forecasted power measurements from 2018 were used. Four different types of CI are analyzed, two that are provided by the sky camera and are known in literature and two developed by R&D Nester.

Title:	*"The Use Of Probabilistic Forecasts"*

Published in:	2019 November/December Issue of IEEE Power and Energy (Magazine Issue 2019 November/December)	
Authors:	Sue Ellen Haupt, Mayte Garcia Casado, Michael Davidson, Jan Dobschinski, Pengwei Du, Matthias Lange, Timothy Miller, Corinna Möhrlen, Amber Motley, Rui Pestana, and John Zack	
Keywords:	probabilistic forecast	

Abstract:	Much of the electric system is weather dependent; thus, our ability to forecast the weather contributes to its efficient and economical operation. Climatological forecasts of meteorological variables are used for long-term planning, capturing changing frequencies of extreme events, such as cold and hot periods, and identifying suitable locations for deploying new resources. Planning for fuel delivery and maintenance relies on sub seasonal to seasonal forecasts. On shorter timescales of days, the weather affects both energy demand and supply. Electrical load depends critically on weather because electricity is used for heating and cooling. As more renewable energy is deployed, it becomes increasingly important to understand how these energy sources vary with atmospheric conditions; Thus, predictions are necessary for planning unit commitments. On the scales of minutes to hours, short-term now casts aid in the real-time grid integration of these variable energy resources (VERs).

Title:	*"Solar Power Forecast Using Satellite Pictures"*

Published in:	37th Photovoltaic Solar Energy Conference and Exhibition (Virtual, 07-11 September 2020)	EU PVSEC
Authors:	João Esteves, Nuno Pinho da Silva, Rui Pestana, Yang Cao	
Keywords:	solar forecast; satellite pictures	

Abstract:	With the new electricity market designs reaching shorter gate closers, the importance of forecast tools for solar energy is of significance importance. One of the methodologies that are being study in the literature is the use of satellite pictures. The satellite pictures provide a wide area monitoring of an electricity asset due to their top-down wide range nature. In the case of renewable solar energy, it can assist the decision-making in the continuous market, which occurs in an hourly basis. In this paper, it is presented a forecast methodology based on satellite pictures, which computes a cloud index. Using theoretical solar radiation of clear sky and the cloud index, the solar power forecast is calculated. The cloud index is calculated using a clear sky library, built using satellite pictures and solar PV aggregation metering data from the region under study. This library defines the probability density distribution that characterizes the clear sky for each hour. Thus, the cloud index is calculated by comparing the probability density distribution of the new picture with the clear sky library.

Title:	*"Identification of Clouds Using an All-Sky Imager"*

Published in:	IEEE - PowerTech 2021 (Virtual, 28 June – 02 July 2021)	PowerTech MADRID 2021 POWER FOR THE SUSTAINABLE DEVELOPMENT GOALS
Authors:	João Esteves, Yang Cao, Nuno Pinho da Silva, Rui Pestana	
Keywords:	all-sky imager; cloudiness; image processing; solar forecast; ultra-short-term forecasting	

Abstract:	With the increasing number of utility-scale photovoltaic power plants, the uncertainty and volatility in power generation increases in the electricity system. In the range of long to medium term forecasting, the literature and the industry have several tools and methods in process. Nevertheless, the current and future energy transition, for instance the shorter gate closer of energy markets, is increasing the need for tools to support the ultra-short-term forecasting. This paper proposes a tool to support the ultra-short-term forecasting using an all-sky imager to map the clouds in the sky and estimate a Cloud Index.

Title:	*"Cloud Height Estimation Using All Sky Imagers"*

Published in:	38th European Photovoltaic Solar Energy Conference and Exhibition (Virtual, 06-10 September 2021)	EU PVSEC
Authors:	João Esteves, Rui Pestana, Yang Cao, Nuno Pinho da Silva	
Keywords:	all-sky imager; solar power; cloud height estimation	

Abstract:	The solar forecast research continues to increase in the academic and industry world to provide tools and methodologies with increasingly performances. The levels of penetration of this renewable energy source is growing and more optimized tools are needed in order manage the electrical grid in a proper and safe way. With the new electricity market designs reaching shorter gate closers, emphasizing the importance of forecast tools for solar energy. The use of all-sky imager (ASI) applied to the solar forecast is one approach being researched in the industry. The ASI images provide a bottom-up approach and in the case of renewable solar energy, it can assist the decision-making by allowing an almost-real time knowledge of the sky and cloudiness behavior. In this work, it is presented a methodology that allows to estimate the cloud height using two ASI installed in two neighborhood photovoltaic power plants.

Title:	*"Wind Power Forecasting with Machine Learning: Single and Combined Methods"*

Published in:	20th International Conference on Renewable Energies and Power Quality (ICREPQ'22) (Vigo, Spain, 27-29 July 2022)	EA4EPQ
Authors:	J. Rosa, R. Pestana, C. Leandro, C. Geraldes, J. Esteves, D. Carvalho.	
Keywords:	wind power forecast; feature engineering; machine learning; ensemble models; recurrent neural network	

Abstract:	In Portugal, wind power represents one of the largest renewable sources of energy in the national energy mix. The investment in wind power started several decades ago and is still on the roadmap of political and industrial players. One example is that by 2030 it is estimated that wind power is going to represent up to 35% of renewable energy production in Portugal. With the growth of the installed wind capacity, the development of methods to forecast the amount of energy generated becomes increasingly necessary. Historically, Numerical Weather Prediction (NWP) models were used. However, forecasting accuracy depends on many variables such as on-site conditions, surrounding terrain relief, local meteorology, etc. Thus, it becomes a challenge to obtain improved results using such methods. This article aims to report the development of a machine learning pipeline with the objective of improving the forecasting capability of the NWP's to obtain an error lower than 10%.

Title:	*"PV Very Short-Term Power Forecasting Method Based On Cloud Monitoring Data"*

Published in:	WCPEC-8 - 8th World Conference on Photovoltaic Energy Conversion (Milan, Italy, 26-30 September 2022)	
Authors:	João Esteves, Rui Pestana, Yang Cao, Nuno Pinho da Silva, Zheng Wang.	
Keywords:	solar forecast; all-sky imager; cloudiness; image processing	

Abstract:	In the wake of climate change, more attention is being focused on green energy production. Renewable energy resources play an important role in the goal of reducing greenhouse gas emissions as they allow the reduction of fossil fuel use. One method to produce energy in a sustainable way is to make use of photovoltaic (PV) panels, which convert the solar energy directly into electricity. Even though the deployment of solar energy production contributes to the decarbonisation of the energy system, it also has its obstacles. The power that can be generated by PV units is proportional to the amount of irradiation reaching the PV panels, which introduces high levels of uncertainty and volatility. In this work, a PV power forecast method based on cloud monitoring data is presented to tackle the very short-term forecast horizon (up to two hours-ahead). The developed methodology uses an all-sky imager (ASI) installed in a solar PV power plant located in the South of Portugal.

B. INTEGRATION OF RENEWABLE ENERGY SOURCES IN THE ENERGY SYSTEM

The increase of energy originating from renewable sources in the energy system, together with the variable nature of its power production pattern, triggers the challenge of their integration in the system.

Such integration encompasses several dimensions. On one side, it relates to the coexistence with other energy sources in the system and the matching of the aggregated supply of energy with the aggregated demand for energy in any particular moment. Since the variable energy source (e.g., wind or sun) is not human-controlled, the injection of renewable energy in the system is, to a large extent, not scheduled. This is particularly true in a context where storage is not ubiquitously available in an efficient manner. Therefore, as opposed to a system with non-variable sources where the flow of incoming energy is controlled, the operation of the system must be capable of reacting to the mentioned fluctuations. This includes the dimensioning of back-ups and reserve capacity to activate when the variable sources fail to contribute to the energy generation, the identification of the most efficient actions to perform when the renewable generation is in excess of what the system can absorb in a certain moment maintaining the adequate characteristics of the electricity signals, and the quasi real-time management of assets whose capacity can depend on atmospheric conditions (e.g., overhead lines).

On another side, the planning of the system and the capacity limits of each element of the grid must be dimensioned taking into

consideration the non-deterministic, stochastic, behavior of the variable generators and of the variable flows of energy in the system.

In our work below, we address some of these challenges, which are relevant to several energy system players. System operators have to address the short-term and day-ahead challenges associated with the presence of variable renewable energy sources, network owners and operators have to ensure the appropriate planning of assets, power producers have to adequately address and manage the risks of variable energy fluctuations and policy makers need to adjust existing and new regulations and frameworks.

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Title:	*"Wind Power Curtailment Optimization For Day-Ahead Operational Planning"*

Published in:	IEEE PES Innovative Smart Grid Technologies Europe Conference 2016 (Ljubljana, Slovenia, 06-09 September 2016	
Authors:	Rui Alves, Francisco Reis, Shen Hong	
Keywords:	wind power curtailment; day-ahead operational planning; evolutionary particle swarm optimization	

Abstract:	In this paper a day-ahead operational planning methodology, for deciding how much wind power to curtail and where, is presented in order to support the wind power curtailment decision-making by system operators under scenarios of network bottlenecks. The Evolutionary Particle Swarm Optimization algorithm is used to provide robust wind power curtailment solutions at minimum cost. The methodology is validated on a case-study based on the Portuguese transmission system. Obtained results show the capability of the methodology to achieve near optimal curtailment solutions when applied to large-scale power systems.

Title:	*"Stochastic Optimal Operation Of Concentrating Solar Power Plants Based on Conditional Value-At-Risk"*

Published in:	8th DoCEIS 2017 Conference (Caparica (Lisbon), Portugal, 03-05 May 2017)	
Authors:	João Esteves, Hugo M.I. Pousinho, Victor M.F. Mendes	
Keywords:	concentrating power plant; conditional value-at-risk; day-ahead market; stochastic programming	

Abstract:	A stochastic programming approach is addressed in this paper, using a risk measure defined by conditional value-at-risk, to trade solar energy in a market environment under uncertainty. Uncertainties on electricity price and solar irradiation are modelled by a set of scenarios obtained by simulation and scenario-reduction. The short-term operational problem of a concentrating solar power plant is given by a mixed-integer linear program, which allows modelling the discrete status of the plant. To increase the operational productivity of the plant during the non-insulation periods, energy storage systems are considered. The goal is to obtain the optimal operation planning that maximizes the total expected profits while evaluating trading risks. For risk evaluation, the conditional value-at-risk is used to maximize the expected profits of the least profitable scenarios. A case study is used to demonstrate the effectiveness of the proposed approach.

Title:	*"Grid-Driven Tool For Renewables Integration Based On Nodal Capacity Allocation"*

Published in:	23rd ICE/IEEE ITMC Conference (Madeira Island, Portugal, 27-29 June 2017)
Authors:	Nuno Amaro, Francisco Reis
Keywords:	capacity; network planning; genetic algorithms; renewable energy

Abstract:	Over the last years, most countries in the world are facing a growing integration of renewable energy sources in their power networks due to the continuous effort on decreasing their carbon footprint. This increasing penetration of renewable energy sources led to the emergence and consequent grow of distributed generation units. From a network planning and growth perspective, the increase of producing centers has different challenges. Additionally, system operators must know and sometimes publish the grid capacity to receive new generation units. Taking this into account, this paper presents a tool that can be used to determine the capacity for reception of new energy sources in the different grid nodes. The tool uses genetic algorithms and power systems analysis software to perform this nodal capacity allocation and its validation is presented through the application of a case study.

Title:	*"R&I Needs And Challenges For a Future Reliable, Economic And Efficient SG System Taking Into Account Microgrids And Local Energy Communities To Support The EU Energy Transition"*

Published in:	CIRED Workshop 2018 (Ljubljana, Slovenia, 07-08 June 2018)
Authors:	Raphaël RINALDI, Ricardo PRATA, Rui Alves et al.

Abstract:	In its Research and Innovation Roadmap, targeting a 10 year period from 2017 to 2026, the European Technology and Innovation Platform for Smart Networks for the Energy Transition (ETIP SNET) defines long-term priorities for investment in Research and Innovation (R&I) activities within the European energy sector. Priorities are established having in mind the EU energy strategy and the expected future challenges of different stakeholders in the energy value chain. Complementarily, the ETIP SNET prioritizes the R&I activities with an Implementation Plan (IP), based on the R&I Roadmap, for the short-term, in which a 3-year period, from 2017 to 2020, is considered. This paper will focus on the microgrid and local energy communities' aspects that are tackled in the ETIP-SNET Roadmap and Implementation Plan.

Title:	*"Evolutionary Capacity Allocation Tool To Safe Grid Integration Of Renewable Energy Sources"*

Published in:	SEST 2018 Conference (Sevilla, Spain, 10-12 September 2018)	SEST
Authors:	Nuno Amaro, Francisco Reis	
Keywords:	nodal capacity; grid planning; genetic algorithms	

Abstract:	The increasing integration of renewables and the advent of smart grids in most countries is leading to a growing number of generation nodes in power systems – distributed generation. System operators must cope with this change and from a network planning perspective, this increase of generation units presents technical challenges. One of these challenges is related to the need that system operators have to be able to know the RES integration capacity at node level, here defined as nodal capacity both in normal and under contingency conditions. This paper presents a tool that calculates the security constraint nodal capacity value of a set of nodes in a power system. Due to the non-convex nature of this problem the tool uses combinatorial optimization methods to be able to assess the nodal capacity values. Results obtained by applying it to the IEEE-300 bus test system are presented.

Title:	*"ETIP-SNET Vision 2050 - Integrating Smart Networks For The Energy Transition"*

Published in:	CIRED 25th International Conference on Electricity Distribution (Madrid, Spain, 03-06 June 2019)	CIRED
Authors:	Raphaël Rinaldi, Ricardo Pastor, et al.	

Abstract:	Since 2014, the European Union's strategy is clearly formulated: we need to drive a clean, secure and efficient energy transition to face climate and energy challenges. It is reinforced by the strong commitment of the European Union to the 2015 Paris Agreement. Therefore, in November 2016, the Commission proposed an ambitious "Clean Energy for All Europeans" package. Therein, all relevant meetings, summits and measures started from a simple observation: "It is in everyone's long-term interest to have a rapid and orderly transition towards a cleaner, more sustainable and less carbon intensive energy future." However, this apparently simple observation requires us to consider numerous challenges: i) Moving towards a low carbon energy sector; ii) Creating a pan European integrated energy system and iii) Mobilizing public and private sectors by iv) Maintaining and extending Europe's industrial leadership. This paper describes the Vision 2050, as elaborated by the European Technology and Innovation Platform of Smart Networks for Energy Transition (ETIP SNET).

Title:	*"Analysis and Inspiration Of The National Load All Powered By Renewable Energy In Portugal"*

Published in:	ISGT ASIA 2019 Chengdu, China, 21-24 May 2019
Authors:	Wei Yang, Rui Pestana, João Esteves, Francisco Reis, et al.
Keywords:	renewable energy development; grid-connected technology

Abstract:	Since the beginning of the 21st century, under the guidance of relevant environmental protection targets of the EU and relevant Portuguese supporting laws and regulations, the renewable energy has developed rapidly in Portugal, and the Portuguese power generation system has developed steadily towards the carbon-free hybrid power generation system. In recent years, the Portuguese power grid has experienced three times of 100% renewable energy to support the continuous operation of the national power load for several days. It appeared twice in 2016, which was the continuous network load of renewable energy supply for 96 consecutive hours in February 2016. In May 2016, it was 107 hours of continuous renewable energy supply nationwide. The most recent one occurred on March 9, 2018, with 63 hours of continuous energy supply to the Portuguese national load. The successful accommodation of large-scale renewable energy in power systems is a systematic project. It relies on energy planning, national transmission network planning, operation and control technologies, and market mechanisms to support all renewable energy across the country.

Title:	*"The Current Status And Experience Of Renewable Energy Development In Portugal"*

Published in:	2019 Chinese Control And Decision Conference (CCDC) (Nanchang, China, 03-05 June 2019)
Authors:	Wei Yang, Rui Pestana, Xing Zhang, João Esteves, Yan Li, Francisco Reis
Keywords:	renewable energy development; grid-connected technology

Abstract:	Portugal has extensive expertise and decades of practice in the field of renewable energy grid-connected technology. In particular, in the past ten years, much more rich experiences have been gained in large-scale grid-connected operation and management of renewable energy. The level of renewable energy operation control is very high in Portugal. Recently, the Portuguese power grid has experienced three times of 100% renewable energy (hydropower, biomass, wind power, PV power, etc.) to support the continuous operation of the national power load for several days. The successful consumption of large-scale renewable energy in power systems is a systematic project. It relies on energy planning, national transmission network planning, operational and control technologies, and market mechanisms. The current status of Portugal's renewable energy development and its related experience are analyzed in this paper.

Title:	*"Fostering Offshore Wind Generation Through Grid Nodal Capacity Calculation"*

Published in:	Wind Energy Science Conference (WESC) 2019 (Cork, Ireland, 17-20 June 2019)	
Authors:	Nuno Amaro, Francisco Reis	
Keywords:	offshore wind; grid planning; nodal capacity; genetic algorithms	

Abstract:	The calculation of the nodal capacity of different grid nodes represents a non-convex problem, requiring optimization techniques to reach optimal or near optimal solutions. R&D Nester developed a tool that uses genetic algorithms to maximize the total amount of energy that can be integrated at the grid level, calculating the nodal capacity in different selected grid nodes and ensuring a safe integration by respecting typical grid planning and operational studies, including grid contingency analysis. In this paper, following the studies being performed in the ARCWIND project, R&D Nester applies this nodal capacity allocation tool to a real power system (part of the Portuguese Transmission Network) to verify the amount of power that can be injected in the grid.

Title:	*"Optimizing Nodal Capacity Allocation Using Risk Assessment Of Element Failure Rate"*

Published in:	IEEE CPE-POWERENG 2020 (Virtual, 08-10 July 2020)	
Authors:	Nuno Amaro, Francisco Carrola, Francisco Reis	
Keywords:	nodal capacity allocation; grid failure rates; smart contingency analysis; grid planning	

Abstract:	The increasing number of grid connection requests from energy producers is resulting in the need to have more adequate tools to calculate the capacity that power systems have to absorb power from new sources in a grid planning stage nodal capacity of different grid nodes. These nodal capacity values can be calculated using different contingency analysis strategies, which usually range from normal operating conditions (N) to N-1 analysis. In this paper, we present a new method to calculate the nodal capacity of different grid nodes which uses a smart contingency analysis based in the failure rates of different grid elements. Results obtained are then compared to those gathered using either an N or an N-1 analysis to check the effect of this new method in the value of nodal capacity in a power system, using the IEEE-6 Bus system as test case.

Title:	*"Impact Of The Dynamic Line Rating Analysis In Regions With High Levels Of Wind And Solar PV Generation"*

Published in:	2020 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe) (Virtual, 26-28 October 2020)	
Authors:	António Couto, Joaquim Duque, Hugo Algarvio, Ana Estanqueiro, Rui Pestana, João Esteves, Cao Yang	
Keywords:	renewable energy integration; wind and solar power generation; DLR; cable thermal balance; conductor temperature; overhead power lines	

Abstract:	Power system operators traditionally use a static transmission line rating method to ensure the electric grid operates under a pre-defined limit temperature of the conductors. This method normally assesses the maximal power capacity of each line using conservative constant weather conditions that usually underestimate the real transmission capacity of overhead power lines. Dynamic line rating (DLR) analysis represent a safe and cost-efficient way to deal with existing congested networks and allowing further integration of current/future renewable generation in many regions. This work applies a DLR tool to identify the power lines' additional theoretical capacity obtained by using this methodology for two Portuguese regions with distinct conditions regarding i) weather, ii) topography and iii) wind and solar power resource. The capacity values obtained are presented, and a comparison with the traditional values obtained from the static methodology used by the Portuguese system operator is established. Results show that the dynamic approach enables significant gains in the line rating for both regions and its use can be extended to regions with high solar resource since the induced cooling effect is also observed in those regions.

Title:	*"Grid Capacity For Floating Offshore Wind Integration – The Portuguese Case"*

Published in:	Developments in Renewable Energies Offshore (*ISBN 9781003134572*, 1st Edition, 2020)	
Authors:	Nuno Amaro, Aleksandr Egorov, Francisco Reis	

Abstract:	the increase of grid connection requests from energy producers results in the need to have more adequate tools to calculate the capacity that power systems have to absorb new dispersed energy sources. Under the frame-work of the ARCWIND project, areas of high potential for deployment of floating offshore wind farms have been identified and there is the need to check the capacity that existing power systems have to absorb possible new sources located in these regions. In this paper we present a study performed for the Portuguese continental territory, calculating the nodal capacity of multiple grid nodes located near the identified areas of interest. These nodal capacities are calculated using realistic models of the Portuguese Transmission System and obtained results allow checking the existing grid limitations for the integration of this possible new source of energy in Portugal.

Title:	*"Fostering Offshore Wind Integration in Europe through Grid Connection Impact Assessment"*

Published in:	Journal of Marine Science and Engineering (J. Mar. Sci. Eng. 2022, 10(4))	Journal of Marine Science and Engineering
Authors:	Nuno Amaro, Aleksandr Egorov, Gonçalo Glória	
Keywords:	nodal capacity; offshore wind; RES integration; ARCWIND	

Abstract:	Floating offshore wind energy is one of the solutions which can foster the ongoing climate transition in Europe. ARCWIND project aims to contribute to this topic by considering multiple research activities designed to contribute to the development of multiple floating technologies, identifying high-potential deployment areas while considering their economic viability and the impact that these would have in existing power systems. Regarding the latter activity, a two-step methodology was implemented to first calculate the nodal capacity that existing electricity networks have to absorb energy from these potential new wind farms and secondly to assess the impact at the point of connection. This assessment is performed by identifying grid reinforcement needs, verifying the impact on short circuit current levels and measuring the impact on the existing energy mix at countrywide level. This article includes the description of this methodology as well as its application to six different use cases covering five European countries: Portugal, Spain, France, United Kingdom and Ireland. Results obtained seem to indicate that in most cases, the current power systems have enough capacity for the possible connection of new floating offshore wind farms without major reinforcement needs and that these wind farms can have a major contribution to the countries energy mix and to the achievement of established climate targets.

Title:	*"System-Wide Nodal Capacity Allocation Applied to a Spanish Distribution Network"*

Published in:	13th Mediterranean Conference on Power Generation, Transmission, Distribution and Energy Conversion (MEDPOWER 2022) (La Valetta, Malta, 7-9 November 2022)	MED POWER
Authors:	Nuno Fulgêncio, Alexandre Gouveia, Nuno Amaro, et al.	
Keywords:	nodal capacity; renewable energy; electric power systems; network planning	

Abstract:	This paper presents a methodology to evaluate the margin for new nodal capacity allocation in distribution networks, at system level. The method, intended to serve system operators at a planning stage, aims to deliver a decision-support tool for expansion strategies. It unfolds in a three-step approach, including a preliminary non-simultaneous analysis of the candidate nodes to frame the solution space to the problem theoretical limits, a simultaneous analysis of all candidate nodes at once using genetic algorithms, and a probabilistic analysis to overcome the non-convexity nature of the problem. The paper provides a brief context of the problem, the general description of the methodology and the results of its application to a real distribution network, using real data from the operator (Cuerva, Spain).

Title:	*"Building up the Grid Planning Methodology of the Future: the FlexPlan Project – The FlexPlan Regional Cases: 6 Ambitious Regional Cases to Check Grid Upgrade Needs till 2050"*

Published in:	IEEE PES ISGT Europe 2021 (Espoo, Finland, 18-21 October 2021)
Authors:	Nuno Amaro

Abstract:	The Horizon2020 project FlexPlan aims at establishing a new grid planning methodology considering the opportunity to introduce flexibility resources (storage and DSM) in electricity transmission and distribution grids as an alternative to traditional grid expansion. After creating methodology and tools, the project applies them to analyze six regional cases covering nearly whole Europe, aimed at casting a view on grid planning in Europe till 2050. In this way, FlexPlan tries to understand how flexibility can help reducing future grid investments. The project ends up formulating regulatory guidelines for NRAs.

Title:	*"Green Ports – Building a Shore Power Load Model for Simulation"*

Published in:	2022 IEEE International Power and Renewable Energy Conference (IPRECON 2022) (Karungappally, India, 16-18 December 2022)
Authors:	João Esteves, Alexandre Gouveia, Nuno Pinho da Silva, et al.
Keywords:	green ports; electrification of ports; load modelling

Abstract:	With the ever-looming threat of global warming to all life forms, the world is putting effort to achieve carbon neutrality in order to avoid grave consequences to ecosystems worldwide. The maritime industry is part of the vectors able to influence significantly emissions of greenhouse gases. In fact, the maritime industry moves more than 80% of the World trade by volume, which makes it a large and growing source of global greenhouse gas emissions contributing to climate change. The Ships are also a source of pollution to the local communities living near the Ports due to their energy consumption when at berth. At the current date, the most common method to mitigate this problem is to provide the ships at berth electricity from shore side. This paper presents the project greenPORT, which aims to create an energy management system for a green energy Port. After a brief introduction, the state of the art and relevant standards related to shore power and green ports are discussed and then, a Port load curve model is presented. This load model, built through a statistical analysis of real data from the Port of Lisbon from the year of 2019, will form the backbone of a future green port management system.

Title:	*"Generation of Coherent Pan-European Scenario Data"*

Published in:	13 Internationale Energiewirtschaftstagung an der TU Wien (IEWT 2023) (Viena, Austria, 15-17 February 2023)	IEWT 2023
Authors:	Jawana Gabrielski, Aleksandr Egorov, Ulf Häger, Gianluigi Migliavacca	
Keywords:	cross-border exchanges; scenario data; regionalization; geo-spatial analysis	

Abstract:	The integration of renewable energy sources requires grid expansion throughout Europe. Due to the highly interconnected system, line expansions influence the overall power flow, so the system must be considered entirely to ensure optimal decisions. As a full pan-European grid simulation is too complex, the system is split into regional cases, considering coherent cross-border conditions between them. These cross-border conditions are obtained, by running a pan-European simulation, including the spatial distribution of renewable energy sources as well as loads, the subsequent time series generation, and the market simulation. The spatial distribution takes into account the geographies of the different countries.

C. COOPERATIVE SYSTEM OPERATION OF THE POWER SYSTEM

System Operation covers the complete area of activities for operating electric power systems, including security, control and quality in terms of fixed technical standards, principles and procedures, but also the synchronous operation of interconnected power systems.

An adequate power system operation shall be conducted in order to optimize the production and delivery cost and to ensure security of supply. The classic problem aims to optimize the provided power by each group of service generators, leading to an overall minimum cost of power production while satisfying the load and system security. Within the cost function one can consider different types of direct and indirect costs, including losses, energy rerouting, system externalities and sustainability issues, such as environmental aspects. Satisfying load and ensuring security of supply requires, in particular, that congestions are avoided and balancing generation with load is achieved. Also, to aim at an efficient cost of the system it is needed that market-based mechanisms are applied whenever possible, to ensure that the most efficient of competing solutions for each possible challenge (e.g, balancing needs or congestion avoidance) is used. System operation shall therefore strive for providing an infrastructure and mechanisms that allow a well-functioning market.

In most European countries the electricity networks are managed, or operated, by different entities depending on the voltage levels under regulated geographical regional (natural) monopolies. Those managing the very high voltage part of the network are transmission operators, while those managing lower voltages parts of the network are distribution operators. The exact voltage level of split depends on the country. The networks are nevertheless connected between

transmission and distribution networks, within one country or region (and between transmission networks, when connection different countries or regions). Therefore, in order to ensure the appropriate system operation mentioned above, the transmission operators and the distribution operators need to cooperate.

The cooperation between transmission system operator (TSO) and distribution system operator (DSO) becomes increasingly relevant within the context of the ongoing energy transition, as the complexity of the electricity system (and of the energy system in general) increases. This results from developments such as the increase of generation assets connected to the distribution network (e.g., wind farms and solar generation), the integration of storage solutions and devices, the movement of electric vehicles, the more intense fluctuation patterns of generation due to renewable sources, the more active participation of customers (being them residential, commercial or industrial) adjusting their consumption and/or generation patterns, among others.

It is in this context that the TSO-DSO cooperation became a key topic and our work below addresses issues related to architecture and framework for that cooperation, the ICT infrastructure needed, the data that needs to be exchanged and the provision of services between TSO and DSO for such cooperation.

Title:	*"TSOs and DSOs Collaboration: The Need For Data Exchange"*

Published in:	DEMSEE'15 - 10th Jubilee International Conference on Deregulated Electricity Market Issues in South Eastern Europe (Budapest, Hungary, 24-25 September 2015)	DEMSEE'15 BUDAPEST, HUNGARY
Authors:	Rui Alves, Francisco Reis, Caihao Liang	
Keywords:	TSO-DSO cooperation challenges; data exchange; system observability; congestion management; voltage control	

Abstract:	This paper presents common challenges facing Transmission Systems Operators (TSOs) and Distribution System Operators (DSOs), as well as the correlated need for a stronger cooperation between them in an environment of unbundled power systems. It addresses different operational and planning areas where the interaction between TSOs and DSOs is presently scarce, showing, through explanatory case-studies, the benefits of an improved and further structured data exchange among grid operators. Outcomes demonstrate that TSO and DSO information exchange allows improved levels of renewable energy sources penetration, as well as an important contribute to help system operators enhancing both short and long-term system security.

Title:	*"Exploring The Market Value Of Smart Grids And Interactions With Wholesale (TSO) And Distribution (DSO) Markets"*

Published in:	Cigré Session 47 (2018) (Paris, France, 26 August – 31 August 2018)	cigre
Authors:	E. Larose, Rui Alves, et al.	
Keywords:	smart grid technologies; smart grid programs; microgrid; market value; localized	

Abstract:	CIGRE has convened the cross discipline working group (WG) C5.24 with the purpose to explore, and report on accounting methodologies for the market-based value of smart grid developments and their net benefits in the context of electricity markets and commercial risk mitigation. As initial activities, the diverse group of contributors have compiled its collective knowledge and present initial research findings in this paper to contribute to the discussion of the preferential topic, "Localized markets or microgrids interacting with wholesale markets". The examples in this paper illustrate priorities of smart grid programs that influence the value, such as de-carbonization and sustainability, grid resilience, energy security, customer comfort/convenience, powering of economic/industrial zones, diversified investors/owners, optimization of combined heat and power (CHP), district heating and/or cooling, and storage.

Title:	*"Practices And Architectures For TSO-DSO Data Exchange: European Landscape"*

Published in:	IEEE PES ISGT Europe 2018 (Sarajevo, Bosnia and Herzegovina, 21-25 October 2018)	
Authors:	Eric Lambert, Hugo Morais, Francisco Reis, et al.	
Keywords:	observability; protocols; IEC Standards; europe; power systems; planning	

Abstract:	This article gives an overview of TSO-DSO data exchanges when face the challenges posed by distributed energy resources and flexibility services in the distribution grid. Roles of TSOs and DSOs in the coordinated power system architecture are explained and use cases for TSO-DSO data exchange are provided. ICT architecture that supports data exchange in the coordinated power system is presented, with commonly used protocols. Additionally, the application of Internet of Things architecture is presented as a technology enabler for TSO-DSO data exchange in the near future. This paper is based on the H2020 TDX-ASSIST (www.tdx-assist.eu) deliverable D1.1 "TSO-DSO state of the art".

Title:	*"TDX-ASSIST: Beyond State Of Art In TSO-DSO Interoperability – The Portuguese Demonstrator"*

Published in:	CIRED 25th International Conference on Electricity Distribution (Madrid, Spain, 03-06 June 2019)	CIRED
Authors:	Tiago Simao, Leonel Carvalho, Francisco Reis, Gonçalo Glória, Rui Pestana, et al.	

Abstract:	The continuous shift from TSO connected generation to DSO connection generation is presenting new challenges to DSOs and TSOs. Keeping the system up and running in the future requires a more collaborative approach to the issue of DSO/TSO cooperation that has existed so far in the vertically integrated network paradigm. It is possible to use IT tools to make sure both system operators have the relevant information they require to fulfil their mission. TDX-Assist's Portuguese demo helps addressing these issues by focusing on the provision of reactive power services by the DSO to the TSO. A new version of the Interval Constrained Power Flow (ICPF) tool, which takes into account disjoint flexibility areas as a result of the combination of discrete control variables, will be used to evaluate the range of operation points at the primary substations (Figure 1). With this information, the TSO can then select an operation point that will cause minimum impact on the transmission network designing and implementing the information exchange needed to support other dimensions such as operational planning through nodal forecast at nodal level and exchange of maintenance plans in a defined observability area of both system operators.

Title:	*"Survey Analysis On Existing Tools And Services For Grid And Market Stakeholders And Requirements To Improve TSO/DSO Coordination"*

Published in:	5th IEEE International Symposium on Systems Engineering (Scotland, UK, 01-03 October 2019)
Authors:	Mohammed Al-Saadi, Gonçalo Glória, Tiago Simão, Rui Pestana, Aleksandr Egorov, Ricardo Pastor, Francisco Reis
Keywords:	smart grids; users; markets; tools; services; network operator's coordination

Abstract:	In this work, a survey was carried out to identify the current European landscape from grid and market stakeholders' point of view and to improve the coordination between the Transmission System Operators (TSOs) and Distribution System Operators (DSOs). The survey includes two parts, one dedicated to grid's tools and services and other to the market's tools and services. This survey aims to identify exists tools and services in order to adapt them to the future challenges. Based on the survey results, it was identified that major concerns of the energy stakeholders are related with the integration of different platforms used for different purposes (for example, operational planning and real time systems), and how to exchange information/data between parties in an expedited and standardized way. The survey participants see energy storage as the most essential technology in the future energy system, followed by the smart metering, online voltage regulation and demand response services.

Title:	*"INTERRFACE: TSO-DSO-Consumer Interface Architecture To Provide Innovative Grid Services For An Efficient Power System, End Users' Requirements"*

Published in:	CIRED 2020 Berlin Workshop (Virtual, 22-23 September 2020)
Authors:	Tiago Simão, Rui Pestana, Francisco Reis, et al.
Keywords:	interoperability; tso-dso coordination; asm; stakeholder's needs; regulation

Abstract:	The current paper presents the main conclusions of INTERRFACE's work package dedicated to state of the art analysis, which concerned on assessing the needs of users, grids and market, and on analyzing existing tools from these 3 dimensions. H2020 project INTERRFACE aims to remove barriers to unleash the potential of the existing and future resources to be an active part in the power system for the benefit of the customers and grid operators. The work reported in the current article was coordinated by the following partners: the work related with customers', grid's and market players' perspective needs was led by EDPD while the work that addresses existing tools and services at an EU level was led by REN. Moreover, the analysis of the existing market designs, market platforms and control schemes focusing at a European level was led by RWTH, and the study of all relevant regulatory issues that should be taken into account in INTERRFACE was led by FSR. The key findings of this paper allude for the changes needed in the energy sector at various levels, in order to meet the challenges posed by the energy transition.

Title:	*"Distribution Network Reactive Power Optimisation Considering TSO/DSO Coordination"*

Published in:	CIRED workshop on E-mobility and power distribution systems (Porto, Portugal, 02-03 June 2022)	
Authors:	Ricardo Pastor, João Saragoça, Rui Pestana, Gonçalo Glória, et al.	

Abstract:	This paper describes the "Flexibility Scheduler" tool, which performs a Sequence-constrained Optimal Power Flow for the optimisation of the reactive power flow in distribution networks for 24 hours ahead. The tool takes into consideration the available assets at the distribution network, the information from the TSO/DSO interface for the period of optimisation (i.e. 24 hour) and available flexibility assets at the TSO interface substation. This tool aims at minimizing overall losses and re-dispatching costs, at the same time that avoids conflicting actions from both operators. Furthermore, the results from the tool application to 16 test cases are presented and discussed.

Title:	*"Short-Circuit Currents information exchange Between DSO and TSO, an approach from the Portuguese demonstration of the ONENET project"*

Published in:	CIRED 2023 International Conference and Exhibition on electricity distribution (Rome, Italy, 12-15 June 2023)	
Authors:	Gonçalo Glória, Aleksandr Egorov, Mateo Toro-Cárdenas, Rui Pestana, et al.	

Abstract:	The short-circuit current is one of the most important security operational parameters. With the increased penetration of DERs, it is crucial to frequently and periodically monitor it, ideally every 24 hours and with high granularity (e.g., 30 minutes). This paper develops a short-circuit computation methodology to calculate the complete short-circuit current in the TSO/DSO interface nodes (extra high voltage/high voltage (EHV/HV) substations), which could be used for operational planning purposes, considering the active contributions to the short-circuit current originating from both transmission and distribution networks. A TSO-DSO coordination procedure is presented to obtain the day-ahead short-circuit currents forecast. Moreover, two real cases are provided as examples for validation of the demonstrated procedures.

D. POWER SYSTEMS FLEXIBILITY AND STABILITY

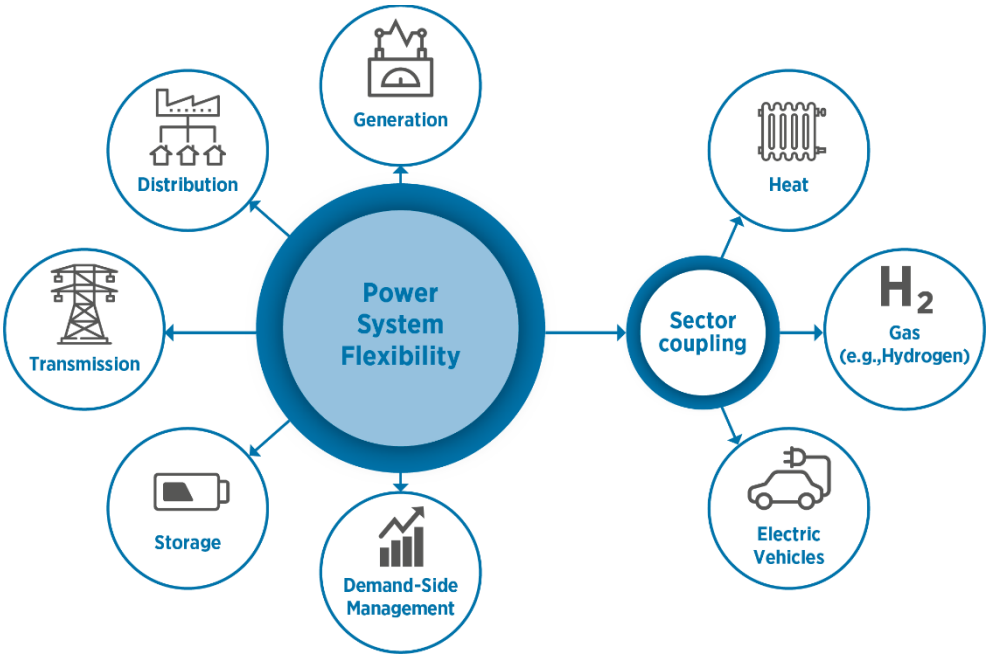
The currently installed power systems largely based on alternate current (AC) require that there is, at all times, an instantaneous balance between generation and consumption in order to keep the AC system frequency (50 Hz in Europe) within a secure range that ensures stability and avoids collapsing of the system. Traditional power systems based on thermal and large hydro power generators largely controlled the output of the generators to ensure that balance. However, during the last decades, aiming at reducing their contribution to the consumption of fossil fuels and the consequent increase in greenhouse gases emissions, the energy systems are integrating an increasing volume of power generators fueled by renewable sources. A significant part of this volume is based on renewable sources that do not guarantee a stable controllable output, such as wind and solar. Therefore, an increasing part of power generation fluctuates over time in a non-controlled manner, in shorter time frames and with more intense fluctuations. To continue to ensure the aforementioned balance between generation and consumption, there is a need to identify controllable mechanisms and elements in the energy system that can adjust to any momentary unbalance, as “escape valves” for the unbalance “tension”, providing flexibility to the system and thus guaranteeing the stability of the system.

This flexibility can come from diverse sources. These include the consumers, who can be provided with mechanisms and incentives to adjust their consumption to the available generation. It also includes the generation side by implementing mechanisms and operation modes that leave some room for controlled operation. Additionally, it includes devices that can be included in the energy system to absorb

and accommodate the fluctuations on the generation side and on the consumption side, such as storage devices (being them chemical, mechanical, or any other type). It can also come from the infrastructure itself, through a coupling of energy systems based on distinct energy carriers, such as coupling the electricity network with the gas network.

Enabling the energy system to integrate all these flexibility sources entails several challenges. On one side, there is a technical challenge to ensure that all these systems cooperate in a sub-second timeframe. Additionally, there is a need to anticipate the expansion of the energy systems taking into consideration this available flexibility. Also, there is a market challenge associated with the potential value of the flexibility provided by the flexibility sources. Worth mentioning is also the regulatory challenge to address this reality.

Many of these technical – operational and planning – , market, economic and regulatory challenges are addressed in our work below.



Title:	*"Frequency Stability Modelling Of The Future Continental Europe Power System"*

Published in:	2017 52nd International Universities Power Engineering Conference (UPEC) (Crete, Greece, 28-31 August 2017)
Authors:	Karel Máslo, Andrew Kasembe, Silvia Moroni, Rui Pestana
Keywords:	frequency control; load modeling; power system stability; HVDC transmission; wind turbines; stability criteria

Abstract:	This paper deals with dynamic simulation focused on frequency stability of the future European power system.

Title:	*"Demonstration Of New Solutions For Provision Of Ancillary Services: Frequency And Voltage Control"*

Published in:	Cigré Session 47 (2018) (Paris, 26 France, August – 31 August 2018)
Authors:	Rui Pestana, João Esteves, D. Jiang, Nuno Pinho da Silva
Keywords:	variable renewable generation; ancillary services; system operation; frequency control; frequency support; voltage control; voltage-droop-control

Abstract:	With the increasing penetration of wind and solar photovoltaic, the system operator may not rely on the remaining synchronous generators to guarantee the frequency and voltage control. These renewable sources of energy must take part in the frequency and voltage control in order to contribute to the electricity grid safety. In the scope of the project "Renewable Dispatch Tool", R&D Nester researched this topic leading to real frequency and voltage tests, on site and in factory environment. The goal of this paper is to show the tests results for wind and PV technology regarding frequency and voltage control tests. Regarding the frequency control tests, frequency-droop-control and inertia emulation tests were conducted for wind and two tests for solar (including the simulation of a real frequency incident in the European electricity grid). The simulation of the feature f-return was also addressed. In the voltage control tests, a test with a real wind farm was performed and a simulation test in factory environment was done for solar. The conclusions are that wind and solar can comply with the "voltage-droop-control" system service; they can also comply with the primary frequency control for over-frequency, by limiting the output power. For under-frequency control, only wind has demonstrated the capability to provide synthetic inertia. For solar PV, local storage might be required to fulfil this requirement. These new solutions will also require a new market design in which the system will have to pay for all system services.

Title:	*"Study On The Demand And Requirements Of Renewable Energy Primary Frequency Control"*

Published in:	2019 Chinese Control And Decision Conference (CCDC) (Nanchang, China, 03-05 June 2019)	
Authors:	Wei Yang, Francisco Reis, Yizheng Xu, Xing Zhang, Yan Li, Xinshou Tian, Rui Pestana	
Keywords:	demand and requirements; primary frequency control; wind power	

Abstract:	The most wind turbines/PV inverters achieve maximum power tracking through converter control, which results in unable to respond to grid frequency changes, unable to help the grid reduce system frequency change rate, and unable to provide active power backup for power systems and increasing the system's frequency control intensity. Based on the fast control of the inverter, the inertia support and primary frequency control to the wind turbine/PV inverter can be realized through the design of the frequency response control. The grid code has been elaborated and implemented in European countries. However, one question is: "Why do we need a frequency regulation of wind power generation?" This paper analyzes the typical cases of renewable energy participation in system frequency control in Europe, and studies the needs of domestic and international renewable energy power to participate in system frequency control. And the frequency control requirements of the Portuguese power grid for grid-connected wind power are given.

Title:	*"Conflict of Interests Between SPC-Based BESS and UFLS Scheme Frequency Responses"*

Published in:	21st International Symposium on High Voltage Engineering (Budapest, Hungary, 26-30 August 2019) Flexitranstore, Special Session in the 21st International Symposium on High Voltage Engineering (ISH 2019), Print ISBN: 978-3-030-37817-2	 
Authors:	M. Eliassi, R. Torkzadeh, M. Mazidi, P. Rodriguez, Ricardo Pastor, et al.	

Abstract:	Nowadays the interest in grid-supporting energy storage systems for frequency response improvement is spurred to increase the penetration of renewable energy resources. Operational frequency constraints of the grid code should be fulfilled in the combined state feedback frequency control provided through the BESS frequency support and UFLS relays. In this paper, favoritism and unfairness of the grid-interactive Battery Energy Storage System (BESS) frequency support is investigated in terms of Rate of Change of Frequency (RoCoF), frequency nadir, time response, steady-state error, and specifically, total load shed subject to power balance over the network. Categorizing load shedding stages into vital and non-vital can measure the appropriateness of the BESS response. Conflicts of the BESS control parameters, performance measures and UFLS actions are verified on the modified Cypriot transmission grid, and the simulation results show that a controller or modulation technique would be essential to coordinate the BESS and UFLS scheme frequency responses to handle conflict of controllers.

Title:	*"Zero Renewable Incentive Analysis For Flexibility Study of a Grid"*

Published in:	21st International Symposium on High Voltage Engineering (Budapest, Hungary, 26-30 August 2019) Flexitranstore, Special Session in the 21st International Symposium on High Voltage Engineering (ISH 2019), Print ISBN: 978-3-030-37817-2	 Springer Professional
Authors:	P. Mazidi, G.N. Baltas, M. Eliassi, P. Rodríguez, R. Pastor, et al.	

Abstract:	Power systems with renewable sources are undergoing various changes to safely accommodate higher share of renewables. In this process, they require different changes ranging from technical characteristics to regulations. In order to manage technicality of the integration of the renewables, storage units play an important role. On the other hand, many countries allocate incentives to the green sources of energy. In this paper, we develop a day-ahead market model that accounts for renewable sources and storage units where no incentive is provided to the renewable sources. Additionally, a flexibility indicator (FLEXIN) is adopted to demonstrate the provided flexibility to the system. FLEXIN is defined by accounting for five sources of flexibility, reserve from conventional power sources, available renewables, storage units, transmission line availability and active demand. The results demonstrate how a system can cope with renewable sources with no incentive in the presence of storage. This paper is part of the Horizon 2020 Flexitranstore project.

Title:	*"Synchrophasor Based Monitoring System For Grid Interactive Energy Storage System Control"*

Published in:	21st International Symposium on High Voltage Engineering (Budapest, Hungary, 26-30 August 2019) Flexitranstore, Special Session in the 21st International Symposium on High Voltage Engineering (ISH 2019), Print ISBN: 978-3-030-37817-2	 Springer Professional
Authors:	R. Torkzadeh, M. Eliassi, Ricardo Pastor, et al.	

Abstract:	Energy Storage Systems installed at primary substations can be used by different participants of the power system for handling the emerging uncertainties caused by supply-side variations, demand-side flexibility and grid topology changes. This work presents a practical design for the monitoring system of the controller of the grid interactive energy storage system. This monitoring scheme takes advantage of synchrophasor measurements gathered by phasor measurement units of wide area measurement systems. The analysis of synchrophasor measurements provides real-time situational awareness over the status of the grid. Therefore, the integration of synchrophasor measurements into the control loop of GI-ESS will enable them to participate in power services of the flexibility market. Furthermore, the implementation of a basic power oscillation damping function as an example of power services using the proposed monitoring system is illustrated in this paper.

Title:	*"Virtual Power Plant – A Multi Service Framework For Coordination Of Centralised Flexibilities"*

Published in:	CIGRE Session 48 (2020) (Virtual, 24 August – 03 September 2020)	
Authors:	R. Martins, R. Pestana, et al.	
Keywords:	flexibility; virtual power plant; RES; integration of renewables; energy markets; ancillary services; hydropower; wind power; storage	

Abstract:	Project EU-SysFlex will study and test the integration of high levels (above 50%) of renewable energy in the pan-European Electricity system by, firstly, identifying the associated technical problems and scarcities and, subsequently, trialling possible solutions for different real environment demonstrators in complimentary contexts across Europe. In this scope, EDP will demonstrate in Portugal – with Siemens as the main technology provider – the coordination of centralized flexibility for the provision of services to the system operator (TSO), through the development of a Virtual Power Plant (VPP). The flexibility will be provided by the combination of intermittent Renewable Energy Sources (RES) with non-intermittent sources (like hydro power plant). REN, the Portuguese TSO, as the Portuguese electric system operator and a member of the project's advisory board provides transversal technical support to the demonstration and will be involved on the upcoming testing phase. The paper details the VPP concept, architecture and the methodology as well as the applications of the concept that can be scalable for different voltage levels and for broader generation portfolios.

Title:	*"Considering flexibility In Network Expansion Planning: Present Practices And Regulatory Conditions"*

Published in:	17th International Conference on the European Energy Market (Virtual, 16-18 September 2020)	
Authors:	Andrei Morch; Nuno Amaro; Gianluigi Migliavacca	
Keywords:	network congestion; planning of network expansion; european regulation; FlexPlan	

Abstract:	There are strong regulatory signals prompting European system operators to consider flexible resources as an active subject in the grid expansion planning. The present paper is based on the first results from H2020 project FlexPlan, namely a European regulatory analysis. The study combines results of literature screening and survey of the existing practices drawing a picture of the present pan-European regulation and political targets to ensure that the subsequent project activities are correctly oriented. The study is structured around several key issues: flexible resources, including consideration of these in planning, ownership of energy storage, cost-benefit analysis, including rules for allocation of costs; Interaction between TSOs and DSOs. The paper concludes that despite strong efforts from ENTSO-E to develop common methodologic principles, there are still several missing elements in the puzzle. This strengthens the importance and proper timing of FlexPlan project, both for testing novel grid planning methodologies coping with the present challenges and providing sound results considering different timeframes.

Title:	*"Implementation Of A Local Flexibility Market For Solving Network Issues"*

Published in:	CIRED 2020 Berlin Workshop (Virtual, 22-23 September 2020)	
Authors:	Luc Richaud, Zoran Marinšek, Isidoros Kokos, Nuno Pinho da Silva, et al.	
Keywords:	flexibility; digitization; low voltage network; renewable integration; virtual power system	

Abstract:	The value of the flexibilities available in an electricity system is often considered for the only sake of balancing production and consumption in a variable environment. For instance, a system with a high penetration of unpredictable renewable energy production requires energy flexibility to keep the balance. However, the activation of a flexibility has not only an impact on the balance of the whole system but also on the electrical network itself. For example, the activation of an energy flexibility to increase consumption – with the goal of absorbing high production of renewable energy facilities – is changing the state of the grid at the location where the energy is being consumed. This impact on the state of the grid can be positive or negative if done blindly. One of the aims of the GIFT project is to address the question of this local impact and the possibility for a distribution system operator to access the flexibility market. It would benefit from it purchasing flexibilities to solve network issues. There are two demonstration sites in the GIFT project, namely the Grytøya island, in Norway, and the island of Procida, in Italy. This study addresses the implementation in the Norwegian demonstration site.

Title:	*"The Innovative FlexPlan Grid-Planning Methodology: How Storage And Flexible Resources Could Help In De-Bottlenecking The European System"*

Published in:	Journal paper ENERGIES (Energies 2021, 14(4), 1194)
Authors:	Gianluigi Migliavacca, Marco Rossi, Nuno Amaro, et al.
Keywords:	grid planning; grid storage; grid flexibility; demand side management; RES integration; European scenarios; regulatory guidelines

Abstract:	The FlexPlan Horizon2020 project aims at establishing a new grid-planning methodology which considers the opportunity to introduce new storage and flexibility resources in electricity transmission and distribution grids as an alternative to building new grid elements, in accordance with the intentions of the Clean Energy for all Europeans regulatory package of the European Commission. FlexPlan creates a new innovative grid-planning tool whose ambition is to go beyond the state of the art of planning methodologies by including the following innovative features: assessment of the best planning strategy by analysing in one shot a high number of candidate expansion options provided by a pre-processor tool, simultaneous mid- and long-term planning assessment over three grid years (2030, 2040, 2050), incorporation of a full range of cost–benefit analysis criteria into the target function, integrated transmission distribution planning, embedded environmental analysis (air quality, carbon footprint, landscape constraints), probabilistic contingency methodologies in replacement of the traditional N-1 criterion, application of numerical decomposition techniques to reduce calculation efforts and analysis of variability of yearly renewable energy sources (RES) and load time series through a Monte Carlo process. Six regional cases covering nearly the whole European continent are developed in order to cast a view on grid planning in Europe till 2050. FlexPlan will end up formulating guidelines for regulators and planning offices of system operators by indicating to what extent system flexibility can contribute to reducing overall system costs (operational + investment) yet maintaining current system security levels and which regulatory provisions could foster such process. This paper provides a complete description of the modelling features of the planning tool and pre-processor and provides the first results of their application in small-scale scenarios.

Title:	*"Optimum Voltage Droop Control in Transmission Systems to Support the Local Voltage Stability with High Share of RES"*

Published in:	IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC) (Virtual, 21-23 November 2021)
Authors:	Rui Pestana, Siam Hasan Khan, C. I. Faustino Agreira
Keywords:	improved voltage droop control; reactive power management at POI; voltage control; voltage droop control

Abstract:	Controlling the voltage profile in transmission systems with a high share of Renewable Energy Sources (RES) is becoming a challenge especially in areas where the presence of RES connected to (Very High Voltage) VHV substations is high. In fact, the local management of the reactive power of each wind power plant connected to a VHV/HV substation should be coordinated not only at the Point of Interconnection through tap regulation, amid others, but also at the individual wind power plant and photovoltaic plant. Based on a real case study in the Portuguese national transmission system, this paper presents the advantage of applying a voltage droop control strategy to avoid conflictual set-point for each wind power plant or photovoltaic plant. Different scenarios, both topological and operational, will be analyzed and developed in order to come up with a robust voltage droop control strategy that mitigates voltage fluctuations at the point of interconnection (POI) by fully utilizing the voltage regulation capability of each Wind Power Plant and photovoltaic plant. The main aim is to ensure that with the implemented control strategy the voltage stays within its steady-state limits in all performed scenarios.

Title:	*"Grey-Box Model For Identification Of Low-Frequency Oscillation Modes In Power Systems"*

Published in:	3rd SEERC Conference Vienna 2021 (Virtual, 29 November to 02 December 2021)	cigre SEERC
Authors:	Mohammed AL-SAADI, Ricardo PASTOR, Nuno AMARO, João SARAGOÇA, et al.	
Keywords:	grey-box model; power system stability; low-frequency oscillation	

Abstract:	The low-frequency oscillation (LFOs) is a common problem in the power systems worldwide. In this paper, an algorithm based on a grey-box model for the identification of low-frequency oscillation (LFO) modes in power systems is presented and validated using IEEE 39 bus system. The output of the grey-box model is a database of the potential low-frequency oscillatory modes, which result from several simulation cases established for a set of network scenarios applied to the power system. These simulation cases include bus bar fault, line fault, generator trip, and load trip. The LFOs are characterized in terms of rotor frequency and magnitude. Ultimately, the objective of the algorithm is to transfer the database information into a black-box model, which is receiving real-time measurements from the grid. Then, the black-box model will update the settings of the dynamic power system stabilizers (PSSs) than will adjust their response accordingly. The paper describes the grey-box model developed and discusses its use in low-frequency oscillation detection.

Title:	*"Cross-Border Flexibility Prequalification Of DER And EVs Based On Decentralized Communication Mechanisms For The Distribution System Operation"*

Published in:	CIRED workshop on E-mobility and power distribution systems (Porto, Portugal, 02-03 June 2022)	CIRED
Authors:	Francisco Silva, Rui Pestana, Gonçalo Glória, João Saragoça, Aleksandr Egorov, et al.	

Abstract:	The adoption of battery-powered electric vehicles in the EU is expected to grow to 30-40 million by 2030. This, together with the large adoption of other Distributed Energy Resources (DERs), represents a great challenge for Distribution System Operators (DSOs) in multiple perspectives, such as providing the needed charging infrastructure and ensuring that everyone is served with the expected Quality of Service (QoS), by having a secure and reliable system operation capable of mitigating grid congestion and voltage violation events. This paper proposes harmonizing the coordination of the prequalification process for flexibility provision (product and grid prequalification) among System and Market Operators from Portugal, Spain and France, enabling the participation of flexibility providers in multiple markets from cross-border countries through a harmonized and non-redundant prequalification process.

Title:	*"The Iberian System through Coupled Simulation of Electrical and Natural Gas Network System"*

Published in:	ENERGYMEET2022 (Copenhagen, Denmark, June 20, 2022)	ENERGYMEET2022 INTERNATIONAL MEET ON POWER AND ENERGY ENGINEERING
Published in:	International Conference on Electrical, Computer and Energy Technologies (ICECET2022) (Prague, Czech Republic, 20-22 July 2022)	ICECET
Authors:	Yang Cao, Rui Pestana, João Esteves, Yang Wei, Nuno Souza e Silva, Dandan Wang.	
Keywords:	power-to-X; electricity grid, natural gas; hydrogen	

Abstract:	The new zero carbon paradigm requires more electrification of all energy sectors and coupled synergies with the natural gas infrastructure, in special power to x, since cheaper solar renewable electric power is expected to exceed the electrical consumption needs in the future. The Iberian case is a good example to simulate the entire system (ELE plus GAS), at the transmission level, since it has already a significant contribution from wind and solar, and an aggressive expansion plan for solar plants and more wind production. In the Portuguese case, in some hours of low electric demand, the wind production has already exceeded the load, reinforcing the need to export or to convert to another source of energy (P2X). The Integrated Energy System Analysis Software (IESAS) developed by CEPRI, offers a Graphic User Interface to model the electric and gas transmission grid networks. During this project the Portuguese and Spanish grid were modeled taking also into consideration the natural gas pipeline connection to France, Morocco and Algeria. The Combined Cycle Gas Turbine (CCGT), co-generation and power to gas couples both electricity and gas networks. Cooling and heating systems can also be modeled in the simulator system but the hydrogen functionality will be incorporated in a later stage. The simulations results obtained from IESAS showed that in both electrical and gas grid had high flexibility by cause of the annual variability of the hydro electrical contribution to the energy mix that are backed up by the thermal power in dry years. Furthermore, with the shutdown of coal power plants in Portugal and the reduction verified in Spain, makes the remaining CCGT gain relevance.

Title:	*"FlexPlan: Testing an Innovative Grid Planning Tool using European-wide Regional Cases"*

Published in:	SEST 2022 - 5th International Conference on Smart Energy Systems and Technologies (Eindhoven, The Netherlands, 05-07 September 2022)
Authors:	Nuno Amaro, Aleksandr Egorov, et al.
Keywords:	grid planning; flexibility; storage; RES integration; FlexPlan

Abstract:	The H2020 project FlexPlan considers the development and validation of an innovative grid planning tool. In this paper, we present the methodology used in the simulation toolchain and preliminary results for optimal power flow simulation performed in four different regional cases covering most parts of Europe. An energy scenario, created in the scope of the project, for 2030 is used and results obtained illustrate both the tool capability to run complex simulations and the need for grid reinforcements. Obtained OPF results will be further used in the project to identify grid expansion candidates and solve the grid expansion problem.

Title:	*"The Innovative FlexPlan Methodology to Reap the Benefits of Including Storage and Load Flexibility in Grid Planning: Methodology and Regional Study Cases"*

Published in:	CIGRE Session 2022 (Paris, France, 28 August - 2 September 2022)
Authors:	Gianluigi Migliavacca, Nuno Amaro, et al.
Keywords:	grid planning; grid flexibility; storage; demand side management

Abstract:	In the last years, we are assisting to a high-speed deployment of Renewable Energy Sources (RES) in electric Transmission and Distribution (T&D) grids as well as to an increased penetration of Distributed Energy Sources (DER) in distribution grids. This is making grid planning activities more and more complex and affected by a high level of uncertainty and calls for a deep revision of the consolidated grid planning methodologies applied by the System Operators. On this pathway, the FlexPlan project (https://flexplan-project.eu/) aims at establishing a new T&D grid planning methodology considering the opportunity to install new storage devices as well as to perform a flexible exercise of some loads located in selected grid nodes as an alternative to building new lines. Local compensation of RES generation spikes could allow to reduce the amount of congestion the grid is exposed to with a less expensive and less environment-impacting intervention. This paper first analyses which aspects of the present consolidated grid planning methodologies applied by System Operators are becoming critical and then describes the key aspects of the new FlexPlan grid planning methodology aimed to overcome those criticalities. Then, the paper provides details on the reference scenarios adopted by FlexPlan for the three grid years (2030, 2040 and 2050) and provides the first results for the simulations carried out by each of the 6 regional cases. Finally, the paper provides some conclusions that can be drawn from these studies on the role flexibility will play in Europe in the medium-long term and on the benefits that can be reaped by taking it into account in the transmission and distribution grid planning process.

Title:	*"Enhancing Value Creation in Energy Communities through Flexibility Management and Network Ancillary Services Provision"*

Published in:	European Council for an Energy Efficient Economy (ECEEE 22) (Antwerp, Belgium, 22-23 September 2022)
Authors:	Carlos Patrão, Nuno Pinho da Silva, Nuno Fulgêncio, et al.
Keywords:	energy communities; virtual power plants; smart grid; demand response; artificial intelligence; renewable energy

Abstract:	The Clean Energy for all Europeans policy package has opened the way for a major transition of the European energy landscape towards customer empowerment and local energy markets development. The European Green Deal, the Fit for 55 % package and the European Directives revision are pushing forward Renewable Energy Communities, which will disrupt the energy sector and overcome limitations of existing rigid energy markets. The rise of distributed energy technologies is fostering the development of customer-centered services such as peer-to-peer energy trading. However, adequate tools and business models to interface and engage with energy markets are still lacking. The H2020 FleXunity project is addressing the emerging market needs by developing a technological platform, that combines advanced artificial intelligence algorithms, blockchain technology and demand response services, to exploit new business models that could value the aggregation of small-scale energy assets. Although the concept of these platforms is relatively well known, their real-world implementation and validation is still at an early stage. This paper presents the FleXunity project's main objectives, details of the Virtual Power Plant managing Platform under development and the characteristics of two distinct real world pilot Energy Communities already deployed in the UK and Iberia. It also presents an analysis of the role that Demand Response activities and independent aggregation could play in Energy Communities, and specificallyexplores the role of Demand Response in the balancing markets of Finland, UK, Spain, and Portugal. Focusing on the pilot markets, the project also identifies the most promising balancing services to be provided by Energy Communities, by surveying and framing the existing regulatory qualification requirements.

Title:	*"Grey-box Model for Identification of Low-frequency Oscillation Modes in Power Systems"*

Published in:	CIGRE SEERC Colloquium 2022 (Vienna, Austria, 30 May - 02 June 2022)	cigre
Authors:	Mohammed AL-SAADI, Ricardo PASTOR, Nuno AMARO, João SARAGOÇA, et al.	
Keywords:	grey-box model; power system stability; low-frequency oscillation	

Abstract:	The low-frequency oscillation (LFOs) is a common problem in the power systems worldwide. In this paper, an algorithm based on a grey-box model for the identification of low-frequency oscillation (LFO) modes in power systems is presented and validated using IEEE 39 bus system. The output of the grey-box model is a database of the potential low-frequency oscillatory modes, which result from several simulation cases established for a set of network scenarios applied to the power system. These simulation cases include bus bar fault, line fault, generator trip, and load trip. The LFOs are characterized in terms of rotor frequency and magnitude. Ultimately, the objective of the algorithm is to transfer the database information into a black-box model, which is receiving real-time measurements from the grid. Then, the black-box model will update the settings of the dynamic power system stabilizers (PSSs) than will adjust their response accordingly. The paper describes the grey-box model developed and discusses its use in low-frequency oscillation detection.

Title:	*"E-mobility Deployment and Impact on Grids"*

Published in:	ETIP-SNET (European Technology and Innovation Platform – Smart Networks for Energy Transition) ISBN 978-92-76-53456-3	ETIP SNET
Authors:	Santiago Gallego Amores, Nuno Souza e Silva, et al.	

Abstract:	The number of electric cars, vans, trucks and buses on the world's roads is rapidly increasing, with a larger variety of electric vehicle (EV) models commercially available. Nevertheless, typical users still have concerns when comparing them to internal combustion engine (ICE) vehicles, such as short-range autonomy and higher prices, which are expected to be solved shortly. The development of a suitable charging infrastructure answering the needs of different stakeholders in the electromobility value chain and the adoption of efficient charging processes, especially smart charging, currently represent the major gap to be covered by most of the actors involved in this complex ecosystem.

Title:	*"Power losses in Natural Gas and Hydrogen Transmission in the Portuguese High-pressure Network"*

Published in:	Elsevier Energy (Volume 272, 1 June 2023, 127136)	
Authors:	Inês Silvestre, Ricardo Pastor, Rui Costa Neto	

Abstract:	Nowadays, along with climate emergency, energy shortage is a challenge being faced worldwide. Energy savings play an essential role, for example, by improving energy efficiencies. Transporting natural gas inside pipelines has associated power losses. In this context, this work focuses on developing a computational tool representing the Portuguese high-pressure gas network supplying Portuguese industry. This tool computes the mass flow rate required by each industry and the power losses associated with its supply. Several scenarios are defined and supplying the Portuguese industry from Sines has a power loss of 4.21%. The exportation to Spain has fewer power losses when divided through Campo Maior and Valença do Minho. Filling Carriço Underground Storage has higher power losses associated, but it is advantageous to use the gas stored to later supply the industry. Power losses increase when hydrogen is added to the mixture, and a linear correlation with a slope of 0.1295 is obtained for 0 – 20% of hydrogen in volume. An economic assessment is conducted for producing hydrogen, and Levelised Cost of Hydrogen, Net Present Value, Internal Rate of Return, and Payback Period are 4.99 €/kg, 242.79 M€, 21%, and 5 years, respectively. The Net Present Value is positive for all scenarios, being most sensitive to hydrogen selling and electricity prices. The economic impact on the industry is highly sensitive to the prices considered.

E.ELECTRICITY MARKETS

The electricity "market" is composed of several markets that operate in different timeframes. These include short-term real time market, day ahead market, long-term market, ancillary services market, among other possibilities.

Those markets have been designed and adjusted throughout the past years. The increase of renewable power generators and of renewable energy in the electricity system, is bringing new characteristics to these markets and to its behavior. Indeed, the variable nature of a large part of the renewable sources (e.g., wind, solar) impacts not only the networks and the system operation, as mentioned in the previous sections, but impacts also the markets and its operation.

European short-term electricity markets have been designed in a context of electricity generation where the daily and hourly operational costs (e.g., cost of raw materials such as coal or gas) are a significant part of the cost for a power generator throughout the lifetime of the generation asset (power plant). Therefore, the short-term market mostly remunerates the marginal cost of energy production. However, for renewable generators such as wind farm or solar plant owners the initial investment is the major cost when compared to the operational cost. This situation poses new challenges to the market participants, being it the power generators who sell in the market, the buyers, the entities financing investments or the authorities.

Furthermore, buyers and sellers used to have a high degree of certainty regarding the availability of the energy they anticipated for the short-term future and for the outcomes of their market bids. The volatility nature of variable energy sources however, can increase the risk exposure of market participants leading to an increasing attention

aspects such as timing of bids, costs of deviation penalties, among others.

Additionally, new technology and legislation is allowing new players in the market, such as consumers who can also generate energy. Therefore, there is a need to design the mechanisms under which such players can participate in the electricity market.

In our work below, several of these topics are addressed.

Title:	*"Assessing The Adaption Of Stochastic Clearing Procedure To a Hydro-Penetrated Market"*

Published in:	14th Conference on the European Energy Market – EEM 2017 (Dresden, Germany, 06-09 June 2017)	
Authors:	Nilufar Neyestani, Filipe J. Soares, Rui Alves, Francisco S. Reis, Ricardo Pastor	
Keywords:	hydro units; market clearing model; probabilistic consumption; stochastic programming; wind power	

Abstract:	Vast increase of renewable energy resources' (RER) share in total electricity production have led to evolving studies regarding different aspects of renewables integration. Other than their effects on network, the electricity markets are also affected by uncertain behavior of RERs in the market place. Hence, new approaches for market clearing are investigated. One of the possible solutions is the deployment of stochastic market clearing. However, the adaption of new market models should consider different market characteristics. As a result, his paper assesses the adaption of stochastic market in a hydro-penetrated system. The co-optimized energy and reserve schedule in the day-ahead time frame is derived using the mixed integer linear programming (MILP). The model is tested with Portuguese electricity market data as a real case of hydro-penetrated system.

Title:	*"Market Integration Of Renewables And Multi-Service Storage Applications"*

Published in:	The 7th IEEE International Conference on Innovative Smart Grid Technologies (IEEE PES ISGT Europe 2017) (Torino, Italy, 26-29 September 2017)	
Authors:	Nuno Pinho da Silva, Ricardo Pastor, João Esteves, Rui Pestana	
Keywords:	solar power generation; energy storage; risk analysis; electricity markets	

Abstract:	As supporting mechanisms for wind and solar electricity generation reduce, it is important to understand how the market is integrating this renewable generation, and what technical solutions may aid the transition to market only revenues. After the analysis of the current barriers and opportunities of wind and solar power generation in the electricity markets, this paper focuses on the integration of solar power generation. Through the design and analysis of a case study with real production and market data, the work addresses the question of how better forecasting decreases the investment payback period of these producers, as well as the benefits of resorting to multi-service energy storage applications. The paper introduces a novel approach for multi-service energy storage sizing for applications in solar power plants that exploits the daily cycle of solar power production to explicitly model the provision of secondary and tertiary reserves during the night. The results show a clear benefit of deploying multi-service energy storage applications, namely from partaking in the provision of secondary and tertiary regulation reserves.

Title:	*"Market-Based Bidding Strategy For Variable Renewable Generation In The MIBEL"*

Published in:	15th International Conference on the European Energy Market 2018 (Lodz, Poland, 27-29 June 2018)	EEM18 15th INTERNATIONAL CONFERENCE ON THE EUROPEAN ENERGY MARKET 27-29 June 2018 Łódź, Poland
Authors:	Ricardo Pastor, Nuno Pinho da Silva, João Esteves, Rui Pestana	
Keywords:	electricity markets; risk analysis; solar power generation; wind power generation	

Abstract:	This paper proposes a methodology for the assessment of the economic viability of wind and solar photovoltaic (PV) electricity generation participating in the Iberian Electricity Market (MIBEL) in equal terms with the remaining generators. This work details the remuneration and penalty mechanisms that are applied to RES generators with only market-based revenues participating in the Day-Ahead Market (DAM) of MIBEL. Moreover, this paper presents results from two case studies with RES producers without any kind of subsidies, one focused on a wind energy producer and another focused on a solar PV producer, directly participating in the MIBEL electricity market. Leveraging on probabilistic market scenarios, drawn from the joint distribution of day-ahead electricity prices and imbalance penalties for each hour of the day, the effects of forecast error and bidding strategy in the Net Present Value (NPV) are described and discussed as well as the impact of the current market design.

Title:	*"The Impact Of Shorter Intraday Market Gate Closure On Regulation Reserves"*

Published in:	Cigré Session 47 (2018) (Paris, France, 26-31 August 2018)	cigre
Authors:	Nuno Pinho da Silva, Ricardo Pastor, João Esteves, Rui Pestana	
Keywords:	electricity market; regulation reserve; intraday market; continuous market; technical restrictions market	

Abstract:	This research work quantifies the variation of regulation reserve requirements by reducing the time span between gate closure of intraday markets and physical power delivery in Portugal. Intraday markets and regulation reserves are means of readjust the grid balancing against deviations from the day-ahead market schedule. While the first works ex-ante to the physical power delivery, the second is a real-time mechanism used by the System Operator to secure the energy supply and avoid the curtailment of wind and solar power generation. This work reviews the new intraday market design in connection with the system services' market. Quantitative analysis identifies a significant increase in the activation of regulation reserves for real-time technical restrictions relief when the physical delivery is more than 7 hours away from the end of the intraday negotiation. This happens in two of the sessions of the intraday market. With the integration of the European continuous market model in the MIBEL intraday market design, it is expected these sessions will lose their weight in the system management.

Title:	*"Costs of electric service, allocation methods, and residential rate trends"*

Published in:	CIGRE Technical Brochure C5, WG C5.16 Technical Brochure N° 747, Dec 2018
Authors:	A. Chuang, Nuno Souza e Silva, et al.

Abstract:	The Technical Brochure examines the alignment of retail rate structures with wholesale cost drivers, by clarifying costs of electric service, its components beyond and including energy, and the methods of cost allocation applied in practice. Retail rate structures are examined for alignment with costs incurred in the provision of electric service, along with enabling technology developments supportive of cost alignment.

Title:	*"Wholesale Market Price Caps"*

Published in:	CIGRE Technical Brochure C5, WG C5.23 Technical Brochure N° 753, Fev 2019
Authors:	C. Hendrzak, Nuno Souza e Silva, et al.

Abstract:	Market price caps are a feature of most markets but their purpose, operation and impacts differ depending on the nature of the market, the role of prices in that market and how many markets exist. Working Group (WG) C5.23 was established to examine these issues at the conclusion of WG C5.15, which examined market risk management. This Technical Brochure examines the results of a survey on market price caps and also examines specific markets in case studies.consistently with conventional generation, before the emergence of FLES, they may fail to capture the whole potential of value of FLES. In this report, the Working Group delivers a theoretical analysis of potential value streams and barriers, together with a practical inventory for 14 different countries.

Title:	*"To Socialise Or Not To Socialise The Cost Of Imbalances From Non-Programmable Renewable Generation"*

Published in:	CIGRE Session 48 (2020) (Virtual, 24 August – 03 September 2020)	
Authors:	Nuno Pinho da Silva, João Esteves, Ricardo Pastor, Yang Cao, Rui Pestana	
Keywords:	renewable energy sources; remuneration schemes; imbalance settlement; market design	

Abstract:	This work studies the two different models for integrating non-programmable electricity generation from renewable energy sources in the Portuguese electricity market: guaranteed remuneration, with socialised imbalance costs, and spot market remuneration, without socialised deviation costs. Feed-in tariff (FIT) was the chosen incentive to increase the capacity of wind and solar power plants. The energy produced by these power plants is mandatorily bought by the supplier of last resort (CUR) that offers it in the MIBEL market at 0€/MWh, leveraging the marginal price of the electricity market to balance the cost of the FIT. One further incentive is that wind, solar and small-hydro power producers under the feed-in tariff are not accountable for their deviations from their schedule. Hence, the cost of balancing these producers adds up to the consumers' tariff, thus being socialised.

Title:	*"Comparative Assessment Of Demand Response Participation In Selected European Balancing Markets"*

Published in:	EEM20 – 17th International Conference on the European Energy Market (Stockholm, Sweden, 16-18 September 2020)	
Authors:	Yassmine Maioui, Gonçalo Mendes, Jessica Chaves, Aleksandra Krivoglazova, Nuno Pinho da Silva, Nuno Souza e Silva, et al.	
Keywords:	balancing market; demand response; independent aggregators; reserves market	

Abstract:	This paper presents a systematic analysis highlighting the opportunities and barriers integrating third-party aggregators in selected markets. Accordingly, it develops a critical comparative framework covering the technical entry specifications, and regulatory conditions evaluating the access of small-scale demand response (DR) aggregation. Promising pilots have been implemented across Europe testing small-scale load aggregation in various platforms, including balancing and ancillary services. By exploring the projects in the case countries, challenges have been outlined. The results show that balancing participation is still dominated by conventional generation units i.e. traditional players. Additionally, compensation of concerned stakeholders, namely balance responsible parties, remains unclear. Nonetheless, improvement is noticeable upon selected markets.

Title:	*"Increase Cross-border Capacity to Reduce Market Splitting of Day-ahead Electricity Markets – A Dynamic Line Rating Approach"*

Published in:	2022 IEEE/PES Transmission and Distribution Conference and Exposition (T&D) (Virtual, New Orleans, LA, USA)
Authors:	Hugo Algarvio, António Couto, Joaquim Duque, Ana Estanqueiro, Rui Pestana, João Esteves, Cao Yang

Abstract:	Market splitting (MS) occurs when the expected power flow between different market zones is higher than the cross-border capacity, separating the markets due to congested tie-lines and bringing economic losses to market participants. The cross-border capacity is computed by TSOs/ISOs commonly using a seasonal steady-state line rating (SLR). SLR assumes fixed conservative meteorological conditions throughout the year except for the ambient temperature that can have a fixed seasonal and spatial variation. Dynamic line rating (DLR) analysis using near real-time meteorological data allows to effectively compute the capacity of the lines. This approach uses the CIGRÉ DLR model and is applied to the cross-border tie-lines between Portugal and Spain. During import periods the grid bottleneck is observed in "Lindoso-Cartelle (LC)" tie-lines. For periods of energy export from Portugal to Spain, four tie-lines in the so-called "Douro-I (DI)" region are the ones that trigger market splitting.

Title:	*"Market Coupling in Europe – Principles and Characteristics"*

Published in:	ICPET 2022 - International Conference on Power and Energy Technology (Xining, Qinghai, China, 28-31 July 2022)
Authors:	Ricardo Cartaxo, Ângelo Casaleiro, Ricardo Pastor, Nuno Pinho da Silva, Yang Wei, Nuno Souza e Silva, et al.
Keywords:	bidding zone; day-ahead; internal electricity market for electricity; intraday

Abstract:	This paper investigates the evolution of the European electricity markets that are leading to the development of the internal European market for electricity (IEM). Focusing on the wholesale electricity spot markets (day-ahead and intraday), the work presents the fundamental concepts and the state-of-the-art of the IEM. The IEM results from the coupling of different European electricity markets, with the goal of increasing the global efficiency in sharing resources among a large number of countries, by promoting competition, increasing liquidity and enabling a more efficient use of the electricity generation and transmission resources across Europe. The architecture, operation and products of the coupled day-ahead and intraday markets are described, and an analysis of the single day-ahead coupling prices is done, exposing that there are regions within Europe where price converge often but the persistence of different market designs within the IEM is a barrier for the European-wide price coupling and market integration.

Title:	*"Analysis of the European Day-ahead Electricity Market Coupling Mechanism: Discussion, Modeling, and Simulation"*

Published in:	EEM2022 - 18th International Conference on the European Energy Market (Ljubljana, Slovenia, 13-15 September 2022)
Authors:	Ângelo Casaleiro, Nuno Pinho da Silva, Nuno Souza e Silva, Ricardo Cartaxo, Ricardo Pastor, Wei Yang, et al.
Keywords:	power system simulation; cross-border capacity allocation; market clearing price; ATC; flow-based; EUPHEMIA model

Abstract:	This paper studies the inclusion of grid constraints into the internal European market clearing algorithms, using an optimization-based approach to provide a comprehensive and comparative analysis of different approaches, namely, Available Transfer Capacity (ATC), Flow-Based (FB), and hybrid ATC+FB. Specific EUPHEMIA-like algorithms are developed and the analysis considers both the social welfare maximization and power exchanges feasibility, the latter validated with an AC power flow. The case study includes real network data from Portugal, Spain, France, Belgium and Germany-Luxemburg bidding zones. Market data made available by MIBEL was used to model two compound Poisson processes representing electricity spot market bidding process and to generate five bidding scenarios, with the number of steps adjusted proportionally to the demand and generation in each bidding zone. The network model was built from the data available in the "Input grid datasets for the preparation of the Ten-Year-Network-Development-Plan (TYNDP) 2018", made available by ENTSO-E. The results show that the FB approach presents a higher social welfare value and feasibility when compared to the ATC approach. When considering the ACT values provided by ENTSO-E transparency platform for Iberian Peninsula, as it is done in the Single Day-Ahead Coupling (SDAC), the hybrid ATC+FB approach compares well with the FB approach in terms of both social welfare and AC power flow feasibility.

Title:	*"Analysis of the Interconnection Capacity Calculation Methodologies for the European Electricity Market"*

Published in:	ICPST 2023 - International Conference on Power Science and Technology 2023 (Kunming, China, 5-7 May 2023)	ICPST 2023
Authors:	Ricardo Cartaxo, Ângelo Casaleiro, Nuno Souza e Silva, Ricardo Pastor, Xia Chao, Nuno Pinho da Silva, et al.	
Keywords:	electricity market; congestion management; cross-border capacity calculation	

Abstract:	The interconnected European transmission system for electricity supports the electricity trading across Europe, promoting the maximization of welfare, in particular when the interconnection capacity is enough to take low marginal cost generation, namely variable renewable power generation, into the demand areas where it is scarce. Transmission systems operators (TSOs) calculate the available interconnection capacity for the day-ahead and intraday markets in a coordinated way. This is a key step to enable price-based market coupling between different countries and regions and, therefore, efficient use of electricity from renewable energy sources and effective distribution of the benefits of renewable electricity across Europe. This work addresses the calculation of interconnection capacity between bidding zones by analyzing the processes and comparing the different methodologies used by European TSOs to coordinate the capacity calculation and compute the underlying generation shift keys (GSKs). The paper focus on the Portuguese cross-border transmission capacity with Spain, where the merit order methodology defines the GSKs supporting the calculation of the Available Transmission Capacity (ATC) for the spot market.

F.INTEGRATION OF ENERGY STORAGE IN THE ENERGY SYSTEM

The concept of capturing energy sources in some form for future use when needed is not new. Such an example is an hydropower plant with reservoir, where a primary source of energy is kept and managed for use when other sources are not available or not used. Other such example is the storage of gas in caverns. Coal bunkers have also traditionally been a form of energy storage. These mechanisms allow the storage of energy for periods of days, weeks or months, depending on the characteristics and conditions, and the planning and operation of energy systems is done ensuring that energy, and electricity, in particular, is available when needed, mitigating any temporary scarcity. In general, energy storage allows the capturing of energy sources at one time for use at a later time.

With the ongoing energy transition, and in particular with the decrease of use of fossil fuels, such as coal, and the increased use of non-controllable renewable energy sources, such as wind and solar, to decarbonize the generation of electricity, two phenomena occur. On one side, the storage in the form of fossil fuels (e.g., coal) tends to disappear, increasing the risk of shortage in a future instant (short-term, mid-term or long-term). On the other hand, the non-controllable power generators (such as wind farms or solar plants) may produce electricity in moments when it is not needed. Being it in the short-term or in the longer-term, these situations may create an imbalance between consumption and generation. Therefore, energy storage becomes an increasing relevant topic in the context of the energy transition, being it in the chemical form, such as batteries, or in any other form.

Stimulated by the previous mentioned developments, energy storage technology has become more competitive and more widely available. Indeed, energy storage can have a contribution in the decarbonization angle of the energy transition accommodating an increased penetration of renewables in the energy system than it would be possible without it. Furthermore, storage can also have a contribution to the economic sustainability of the energy transition by allowing to explore alternatives to the traditional grid expansion. In some cases, use of storage may enable a more stepwise, or even replacement, approach to grid expansion. Finally, energy storage also contributes to the reliability and security of the energy system, as it evolves towards a system with more renewable energy sources. Indeed, given the variability of those sources, storage can play a key role in absorbing the existing variations, providing flexibility to the system, and ensure a smooth and technically required balancing between generation and consumption.

The work described below addresses several of these aspects. It includes exploration on how energy storage can be considered as a relevant asset in the longer-term network planning phase, taking into analysis both technical and economical aspects when considered different alternatives. In this sense, a distinction between centralized large-scale storage and distributed smaller-scale storage is relevant. It also addresses the impact of storage on ensuring the security of supply in the short-term operation phase. Finally, it also delves into the regulatory aspects of integrating energy storage in a complex system of regulated and non-regulated agents and into the market related implication of operating such an asset.

Title:	*"Planning Energy Storage In Power Transmission Networks"*

Published in:	IEEE Green Energy and Systems Conference 2014 (California, USA, 24 November 2014)	
Authors:	M. Moreira da Silva; J. Ye; T. Shi; R. Pastor	
Keywords:	energy storage; electricity; europe; investment; power transformers; planning; power system stability	

Abstract:	In this paper an overview is drawn on energy storage technologies and their application on power systems, from the transmission system operators (TSOs) perspective. Potential constraints to energy storage commissioning are identified and possible solutions described. A set of guidelines for planning energy storage in transmission networks is provided, including a survey on regulatory framework. A planning methodology and a case study are provided.

Title:	*"Siting And Sizing Dispersed Energy Storage In Power Transmission Networks"*

Published in:	IEEE Green Energy and Systems Conference 2015 (California, USA, 09 November 2015)	
Authors:	M. Moreira da Silva; R. Pastor, T. Shi, L. Zhao, J. Ye	
Keywords:	energy storage; planning; algorithm design and analysis; power system reliability; reliability; economics; investment	

Abstract:	This paper provides an algorithm for selecting the site and size of dispersed energy storage (DES), in power transmission networks. Firstly, flexibility requirements for each branch are identified through an assessment of the transmission network. From the previous analysis, an evolutionary particle swarm optimization algorithm is applied to find the preferred solution, in terms of DES site and size. The optimization model includes a multi-interval simulation of the network, for a given period of time, in order to include both power and energy requirements. IEEE 14-bus Reliability Test System, with energy storage, is simulated as case study.

Title:	*"Improving Grid Security In The Presence Of A High Penetration Of RES Through Optimal Planning And Operation Of Distributed Energy Storage Devices"*

Published in:	IEEE CPE-POWERENG 2020 (Setúbal, Portugal, 08-10 July 2020)	IEEE CPE-POWERENG Setúbal 2020
Authors:	Ricardo Pastor; Wei Yang; Nuno Pinho da Silva; Sara Rodrigues; Francisco Reis, Xue Jinhua	
Keywords:	planning; energy storage; security; power systems; renewable energy sources; optimization; particle swarm optimization	

Abstract:	In this paper an evolutionary algorithm for the sizing and siting of distributed energy storage systems is presented. The algorithm's objective is to maximize the penetration levels of renewable energy sources present in the network, while maintaining network's security standards. The algorithm is applied for multiple network congestion scenarios and in the presence of high renewable energy production levels. Due to the non-convex nature of the problem the Evolutionary Particle Swarm Optimization (EPSO) was used. Additionally, the intrinsic parameters of the EPSO algorithm were studied and selected in order to optimize its behavior in the search for robust solutions for this problem. Furthermore, the contributions from the algorithm for the provision of extra flexibility to the power system with resort to dispersed energy storage systems are analyzed and tested using IEEE 14 bus network.

Title:	*"The FlexPlan Approach To include the Contribution Of Storage And Flexible Resources in Grid Planning"*

Published in:	55th International Universities Power Engineering Conference (Virtual, 01-04 September 2020)	UPEC 2020 Torino
Authors:	Gianluigi Migliavacca; Marco Rossi; Dario Siface; Nuno Amaro, et al.	
Keywords:	planning; investment; europe; tools; optimization; buildings; mathematical model	

Abstract:	This paper describes the main features of the new European research project FlexPlan. This project aims at establishing a new grid planning methodology considering the opportunity to introduce new storage and flexibility resources in electricity transmission and distribution grids as an alternative to building new grid elements. FlexPlan will create a new innovative grid planning tool whose ambition is to go beyond the state of the art of planning methodologies, by including the following innovative features: integrated transmission distribution planning, inclusion of environmental analysis, probabilistic contingency methodologies replacing the N-1 criterion as well as optimal planning decision over several decades. Then, the new tool will be used to analyze six regional cases covering nearly the whole European continent, aimed at demonstrating the application of the tool on real scenarios as well as at casting a view on grid planning in Europe till 2050.

Title:	*"Regulation and Market Design Barriers Preventing To Capture All the Value from Fast and High-location-freedom Energy Storage"*

Published in:	CIGRE Technical Brochure C5, WG C5.25 Technical Brochure N° 752, Jan 2019
Authors:	Ricardo Pastor, Nuno Souza e Silva, et al.

Abstract:	This document is the result of a collaborative work to identify regulation and market design barriers preventing to fully capture the value from "new" energy storage technologies. The considered storage technologies have the particularity to be faster (ramping rate and response time) and to have higher-location-freedom (installation possible almost everywhere on the grid) than conventional power generation assets. In this document, we call these technologies "FLES" for Fast high-Location-freedom Energy Storage. For example, electrochemical batteries, flywheels and vehicle2grid are in the scope. As current regulation and market design were designed consistently with conventional generation, before the emergence of FLES, they may fail to capture the whole potential of value of FLES. In this report, the Working Group delivers a theoretical analysis of potential value streams and barriers, together with a practical inventory for 14 different countries.

Title:	*"Impact of Energy Storage on Electricity Markets"*

Published in:	IEEE - PowerTech 2021 (Virtual, 28 June – 02 July 2021)
Authors:	Ricardo Pastor

Abstract:	To achieve the decarbonization of the energy sector in the medium-long term (2050), an increase of electricity production from variable wind and solar energy is planned for the power system. This variability needs to be balanced out by flexibility from other resources, such as storage. Several storage technologies are, and will be, available, with different characteristics. Even if there is no storage technology suitable for every application, a best suited technology exists for a specific requested performance, either at generation, transmission, distribution or demand side. The EU long-term vision expects a significative growth of storage, especially, of batteries in the power system. In this context, we will have a look at the opportunities and barriers for storage in the EU in the next years. Storage will have to compete in electricity markets with generation and demand. Therefore, the feasibility of the projects will depend on the services it can provide, on the value of these services and on the cost of the technology. In addition, the demand profile modification caused by a massive penetration of storage will have an impact on electricity markets.

Title:	*"Energy Storage – KPI Assessment and Prioritisation of R&I Targets"*
Published in:	ETIP-SNET (European Technology and Innovation Platform – Smart Networks for Energy Transition) ISBN 978-92-68-00412-8 (Publications Office of the European Union, 2023)
Authors:	Ricardo Pastor *et al*.
Abstract:	This Position Paper 'KPIs for Energy Storage Systems and prioritisation of R&I targets' is an initiative of the ETIP SNET WG2 (Storage technologies and system flexibilities) with the objective of defining a vision for R&D&I of storage technologies and involving stakeholders in this vision. It analyses different energy storage and conversion technologies, focusing on the specific challenges they face and trying to prioritise and suggest R&I actions to overcome them. Performance Goals are introduced and defined to support the analysis and identify the main challenges. A mapping exercise is performed to define priorities and optimise the R&I strategy to overcome them, as well as a set of KPIs to set targets for the years 2025 and 2031. The paper does not consider battery technology, given the comprehensive list of actions already taken at European level to stimulate the European battery industry and to boost the necessary R&I ecosystem.

G. DIGITALIZATION AND MONITORING OF THE POWER SYSTEM

The decarbonization of the energy sector and the associated energy transition led to an increase of complexity of the energy system. This complexity is associated with numerous factors. To name a few, we can consider the deployment of non-controllable power generation, the need for flexibility to accommodate fluctuations in the power generation and ensure a balance between generation and consumption, and consequently, reliability and security of supply, the deployment of storage to contribute to mitigate the challenges that those elements bring to the energy system, the increased number of actors participating in the energy system, the need to coordinate these elements with well functioning markets or the compliance with regulatory requirements. An effective coordination of all these challenges needs an effective and efficient communication between the relevant actors, being it in the longer-term associated with planning activities and visibility and monitoring of different elements, or in the shorter-term associated with time-critical actuations facing events and evolving two or more assets or actors.

With the increase in computing power, miniaturization and communication speed and with the decrease of technological costs, the distribution of computing processing and data storage capabilities across assets, network elements and geographies in the energy system became technologically and economically viable. Furthermore, ensuring that such distributed elements could communicate and exchange needed information under commonly understood languages was necessary to integrate an increasing number and type of actors, with cost-effective solutions and in an effective and efficient way.

Digital communication and standard communication protocols became then relevant tools to address the complexity and the challenges that the energy transition poses to the energy system. Such tools are needed at several levels. At a more elementary and nodal level, such digital communications and standard protocols enable an efficient communication and coordination within a substation among different substation equipments and functionalities. At a higher level, they permit an efficient coordination between distant network elements. Still at a more systemic level, they allow for the coordination among different power system and market participants. The work described below addresses some of these aspects.

Title:	*"A Joint Research On The Substation Of Future Between Portugal And China"*

Published in:	Advanced Power System Automation and Protection Conference (Nanjing, China, 21-23 September 2015)	APAP
Authors:	Ricardo Cartaxo, Fan Chen, Fernando Matos	
Keywords:	IEC 61850; simulation center; RTPSS; IED; PAC system	

Abstract:	The development of Smart Grid promotes the research of the update of the traditional substations. The new standards and technologies, such as the IEC61850, the non-conventional instrument transformers, the communication networks, which can make the substations more intelligent and can bring a lot of benefits for TSO and DSO stakeholders, are recommended to be applied in substations. The joint project 'Substation of the Future', that is being developed by R&D Nester (a research institute owned by REN and SGCC, respectively, the Portuguese transmission system operator and Chinese integrated system operator) has as main goal to integrate the vision, requirements and experience of those utilities and deploy the next generation substation secondary technical specifications, to be applied by both companies.

Title:	*"Enhanced Testing Platform For The Smart Substation"*

Published in:	PAC World Conference 2016 (Ljubljana, Slovenia, 13-16 June 2016)	pacworld PROTECTION, AUTOMATION & CONTROL WORLD CONFERENCE
Authors:	Ricardo Cartaxo, Bruno Soares, Fan Chen	

Abstract:	The R&D Nester investigation centre is currently undertaking the 'Substation of the Future' project, which aims to produce a set of technical specifications for the PAC system of transmission substations, having in mind the concept and the vision of the Smart Substation. Among other, the following aspects are being considered: reliability assessment of critical functions, use of the IEC 61850 at specification level, both station and process level, and a comprehensive design of the substation communication network, considering its impact on the performance of the PAC functions. To make the proof-of-concept of the developed system, a testing platform has been designed, composed by pieces of hardware and software. Furthermore, it is expected that the testing platform will be used in the future for equipment homologation tests by utilities. This paper describes this platform, explaining in detail the function of each one of its modules.

Title:	*"Integrated Simulation Model Of Power System Protection Schemes And Process Bus Communication Networks"*

Published in:	2016 IEEE Electrical Power and Energy Conference (EPEC) (Ottawa, Canada, 12-14 October 2016)	
Authors:	Andre dos Santos, Bruno Soares, Fan Chen; et al.	
Keywords:	substation automation system; process bus; protection scheme; integrated simulation	

Abstract:	An integrated simulation model of power system protection schemes and IEC 61850 process bus communication models was developed for the design of substation automation systems of the future. The model is capable of reproducing a sequence of the relevant events and equipment states under different operation scenarios, including normal operation and power system fault disturbances. The model includes a description of the power system, the protection scheme, including its several intelligent electronic devices, and the process bus communication network. The model allows an assessment of the functional correctness of steady-state operation of the protection scheme as well as during a power system fault clearance process. It also allows the performance evaluation of the underlying communication network. The capabilities of the model are illustrated with an example scenario of power system fault followed by circuit breaker failure.

Title:	*"Using The IEC 61850 Formal Description Capabilities Towards a Vendor-Independent PAC Specification"*

Published in:	CIGRE Joint Colloquium 'Building Smarter Substations' (Mexico, November 2016)	
Authors:	Ricardo Cartaxo, Bruno Soares, André dos Santos, Wei Yang	
Keywords:	IEC 61850; PAC system; specification and configuration tool; engineering process	

Abstract:	The specification of the PAC system has been done until now using natural language, together with drawings, equations and other representations. The use of natural language, however, has two main drawbacks: (i) it may be exposed to interpretation errors and (ii) cannot be directly interpreted by a configuration tool. R&D Nester is a research centre, owned by Rede Eléctrica Nacional (Portuguese TSO) and China Electric Power Research Institute, which is currently undertaking the 'Substation of the Future' project, which aims to develop the specification for the next generation PAC systems. The described methodology to specify and configure the PAC system is the so called top down engineering process, which has the main advantage of providing a specification independent from the manufacturers, driving to a high level of standardization between the several substations of a utility.

Title:	*"Characterization Of Substation Process Bus Network Delays"*

Published in:	Magazine "IEEE Transactions on Industrial Informatics" (Issue 2 2017)	IEEE Transactions on Industrial Informatics
Authors:	André dos Santos, Bruno Soares, Fan Chen,, et al.	
Keywords:	communication delay; generic object oriented system event; IEC 61850; power systems; precision time protocol; process bus; sampled values	

Abstract:	The paper presents the characterization of network delays in an IEC61850 process bus substation area network, both through theoretical analysis and simulations. Several design targets were defined considering the recommendations of standards and good design practices: number of network hops; total network delay; probability of the delay being exceeded; link load; network topology and availability. An analytical delay estimation methodology is proposed, considering both the steadystate traffic and traffic resulting from a breaker failure event. A complete substation is taken as example for characterizing the network delays, considering a star network topology. Simulations allow obtaining the cumulative distribution functions and percentile values of network delays. Results show a good agreement between the simulation and the analytical analysis. While the delay is best characterized statistically through simulation, finding the maximum network delay through simulations can be very time

Title:	*"Co-Simulation For The Evaluation Of IEC 61850 Based Protection Schemes"*

Published in:	Power System Computation Conference (PSCC) 2018 (Dublin, Ireland, 11-15 June 2018)	PSCC 2018
Authors:	André dos Santos, Bruno Soares, Chen Fan, et al.	
Keywords:	power system simulation; ICT simulation; co-simulation; protection system; IEC 61850	

Abstract:	The paper describes a dedicated co-simulation architecture to combine power system (PS) simulation and information and communications technology (ICT) simulation, to assess new protection schemes fully compliant with the IEC 61850 standard. The interaction between the two simulators has been validated by an example showing the generated Ethernet traffic by a simple substation protection scheme under a power system fault condition. Simulation results are presented from the power system perspective, by means of voltage and current oscillography and from the ICT system perspective, using an especially developed sequence diagram of the transferred Ethernet messages. By using the proposed architecture, the time performance of protection schemes based on process bus can be assessed.

Title:	*"Self-recovery Mechanisms For IEC 61850 Substations With Process"*

Published in:	PAC World Conference 2018 (Sofia, Bulgaria, 25-28 June 2018)	pacworld PROTECTION, AUTOMATION & CONTROL WORLD CONFERENCE
Authors:	Ricardo Cartaxo, Bruno Soares, Yang Wei, André Santos, et al.	

Abstract:	The adequate level of reliability of the bulk-power system requires the highest levels of availability and performance from the dedicated protection, automation and control systems (PAC), due to the impact of component failures in the overall system operation. Conventional PAC systems applied in transmission substations are typically composed of, per bay and at least, two independent protection systems and one non-redundant bay control unit for measuring, monitoring and HV equipment control. Furthermore, full independence of the two main protection systems is ensured by separate analogue circuitry and operation of distinct circuit breaker tripping coils. Based on the aforementioned, new architectures and system designs are now being envisioned for the global PAC system. These new systems enable innovative redundancy schemes including self-recovery mechanisms to improve system availability, in case of failure or inconsistent behavior of one or more components, while guaranteeing the security and dependability levels of all required functions as in the conventional designs.

Title:	*"Laboratorial Assessment And Scalability Analysis Of Protection And Automation Functions Supported By a Smart Substation Process Bus Network"*

Published in:	Cigré Session 47 (2018) (Paris, France, 26-31 August 2018)	cigre
Authors:	B. M. Soares, A. Santos, R. Cartaxo, W. Yang	
Keywords:	substation; protection; control; automation; process bus; IEC 61850; hardware-in-the-loop; real-time simulation; quality of service; communication network assessment	

Abstract:	As the IEC 61850 is increasingly being adopted as the communication and configuration standard by IED manufactures, utilities all over the world are deploying more Process Bus networks in their substations. Despite all the advantages broadly analysed in literature, these networks shall be carefully designed, in order to get the maximum benefit without compromising the current levels of reliability, dependability and security of Protection, Automation and Control (PAC) systems. The presented results are a step forward on the implementation of Smart Substations where Process Bus Network will play a crucial role. Since the considered substation topologies are standard, the results are applicable in all geographies.

Title:	*"Remote Monitoring Overhead Lines Using Satellite Images"*

Published in:	CIGRE Session 48 (2020) (Virtual, 24 August – 03 September 2020)	
Authors:	Nuno Pinho da Silva, Isabel Alvite, João Gaspar, Jorge Filipe Martins, et al.	
Keywords:	overhead lines; right of way (ROW) monitoring; fuel management; satellite-based services	

Abstract:	This work presents the two satellite-based services designed to perform remote monitoring and automatic control of the right-of-ways' (RoW) field management activities and for the planning of new critical infrastructures. Remote and continuous monitoring of the right-of-way enables regular updated characterization and provides as well means of detecting possible critical changes of the land-use in the RoW, useful for risk assessment. The automatic control of right-of-ways' fuel management using satellite imagery provides remote evidence of the external service providers' work and enables the implementation of condition-based selective maintenance plans.

Title:	*"Testing Line Differential Protection And Teleprotection Over An IP/MPLS Communication Network"*

Published in:	CIGRE Session 48 (2020) (Virtual, 24 August – 03 September 2020)	
Authors:	J. Caseiro, R. Cartaxo, J. Saragoça, N. Martins, N. Amaro	
Keywords:	IP-MPLS; line differential protection; teleprotection; GOOSE	

Abstract:	In transmission grids, the differential protection and the distance protection, together with teleprotection schemes, are the backbone of the protection system for transmission lines. These functions are able to assure quick acting and selective fault protection. Both line differential and teleprotection functions require real-time wide area communication between the ends of the transmission lines. To meet this requirement, a robust communication network infrastructure is needed, ensuring reliable communication between both ends. The project described in this paper was undertaken by the Portuguese TSO and its associated research centre, gathering the Paris 2020 B5-2222 control (PAC) systems and communication networks, aiming to validate a solution for an IP/MPLS network providing communication services for line protection systems. A testing platform was built, making use of a real time power system simulator (RTPSS), in which protection relays from the three manufacturers/models currently present in the Portuguese transmission grid have been tested. The IP/MPLS setup was built with routers of the manufacturer currently used in the Portuguese TSO's IP/MPLS network, and using optical fiber available in the grid's overhead lines. It was engineered and configured to match the interfaces and protocols used by the protection relays. Additionally, network impairment and traffic generator equipment were used to test the robustness of the solution.

Title:	*"From Specification To The Substation. The OSMOSE Project Contribution To Improve The IEC 61850 Engineering Process."*

Published in:	PAC World Issue Dec/2020 (Magazine Issue December 2020)	pacworld
Authors:	Claudio Silva, Ricardo Cartaxo, et al.	

Abstract:	The OSMOSE project is a H2020 EU funded project answering the call for a 'Demonstration of system integration with smart transmission grid and storage technologies with increasing share of renewables.' The project aims for the development of flexibilities which can be used for a better integration of renewable energy sources (RES).

Title:	*"Implementation And Testing Of A Conformance Platform For IEEE 1901.1 Power Line Communication Standard"*

Published in:	MEIE 2021 - 4th International Conference on Mechanical, Electric and Industrial Engineering (Kunming, China, 22-24 May 2021)	MEIE2021
Published in:	IOPscience Journal (Volume 1983, 12/Aug/2021)	IOP science
Authors:	Nuno Amaro, João Saragoça, Ricardo Cartaxo, Wei Yang, Ren Yi	

Abstract:	IEEE 1901.1 Standard for Medium Frequency (less than 12 MHz) Power Line Communications for Smart Grid Applications was officially released on 2018. This standard brings new possibilities for power line communications, as the used frequency range allows for broader band and higher bit rates when compared to other PLC communication standards. In this scope, this paper presents a conformance platform that allows testing compliance of devices implementing the standard. This conformance-testing platform is then used to test the station and concentrator devices from three different manufacturers, using the data link layer tests as one example, highlighting the capabilities of the platform and simultaneously evaluating the current status of development of these devices (with regards to standard compliance). Results of these tests are also included.

Title:	*"IEEE 1901.1 Power Line Communication Electromagnetic Emission Study"*

Published in:	MEIE 2021 - 4th International Conference on Mechanical, Electric and Industrial Engineering (Kunming, China, 22-24 May 2021)	MEIE2021
Published in:	IOPscience Journal (Volume 1983, 12/Aug/2021)	IOP science
Authors:	Nuno Amaro, João Saragoça, Ricardo Cartaxo, Wei Yang, Ren Yi	

Abstract:	IEEE 1901.1 Standard for Medium Frequency (less than 12 MHz) Power Line Communications for Smart Grid Applications was officially released in 2018. This standard expands the possible applications of Power Line Carriers communications by using a medium frequency technology, allowing for a higher bandwidth and bit rates compared to the current industrially used solutions. As the standard operates below a frequency of 12 MHz, and constituting a new solution in this area, it is fundamental to evaluate electromagnetic emissions and evaluate possible electromagnetic disturbances. In this paper, we pre-sent a methodology to measure electromagnetic emissions of IEEE1901.1 compatible devices. This methodology is then used to measure real emissions from two different IEEE compliant modules from two different manufacturers, including central coordinator and station devices.

Title:	*"Assessing the Performance Of The IEEE 1901.1 Power Line Communication Standard Using OMNeT++"*

Published in:	ICPICS 2021 - IEEE 3th International Conference on Power, Intelligent Computing and Systems (Shenyang, China, 29-31 July 2021)	ICPICS International Conference on Power, Intelligent Computing and Systems
Authors:	João Saragoça, Nuno Amaro, Ren Yi, Ricardo Cartaxo, Wei Yang	
Keywords:	IEEE 1901.1; INET; OMNeT++; PLC; simulation	

Abstract:	IEEE 1901.1 Standard for Medium Frequency (less than 12 MHz) Power Line Communications for Smart Grid Applications was officially released on 2018. This standard brings new possibilities for power line communications as the used frequency range allows for broader band and higher bit rates when compared to other standards. To illustrate the potential of this standard, this paper describes simulations performed with the open source OMNeT++ simulator, using the INET framework, comparing the performance of IEEE1901.1 with PRIME and G3.

H. ANALYTICS FOR THE ENERGY SYSTEM

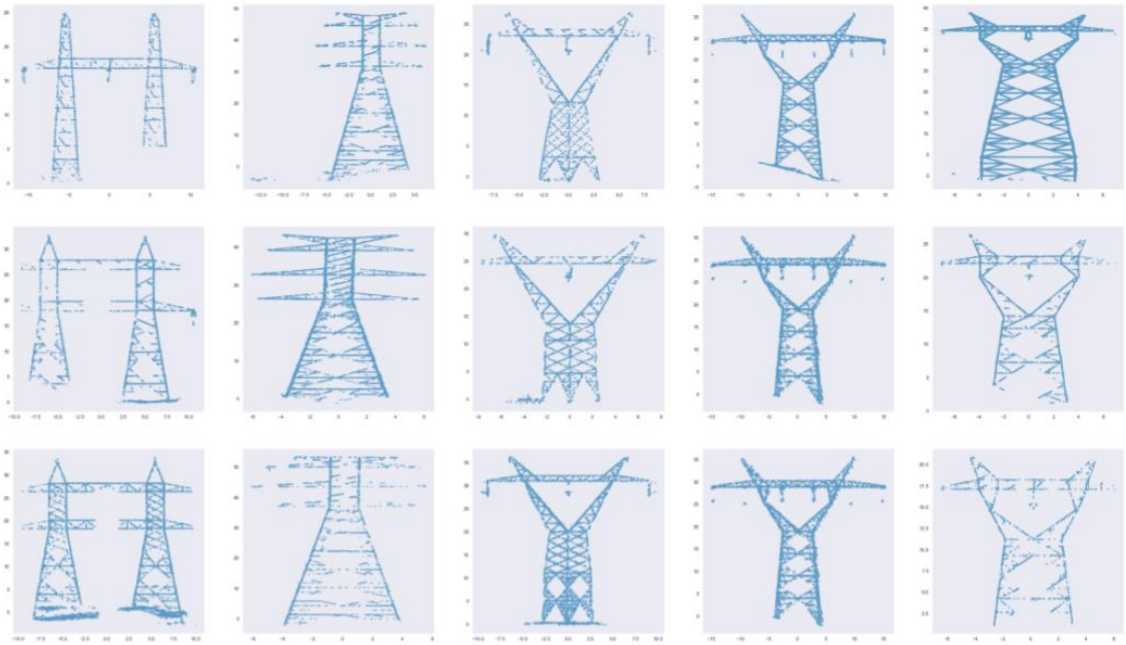
The past decades have witnessed the proliferation in the miniaturization of computing capabilities, increase of communication mechanisms, both wired and wireless, rise of speed of data transfer and reduction of cost of data storage and electronics. This allows for a more ubiquitous placement of sensors and data collection devices, in line with an Internet of Things (IoT) environment, and the consequent collection and processing of data in the energy system.

This availability encounters particularly useful application in the energy systems domain, where the increasing complexity of the system needs amplified support for decision making towards an effective and efficient planning and operation.

Indeed, many domains in the energy system benefit from such approach. System operators need to anticipate the variability of renewable energy sources and of load behavior to prepare for the impact on their daily, hourly and real-time operation. Power producers using renewable energy sources, such as the wind and the sun, need to estimate their future production capabilities in order to make offers in the energy market and avoid being penalized for deviations. Owners and operators of networks and assets need to monitor their devices in order to ensure proper operation and to plan maintenance. Data analytics is key to address the optimization and efficiency of these and many other processes.

Given the large amount of assets involved and the time criticality of many events and processes, the amount of data collected and available often needs to be handled according to big data techniques, due to the volume, velocity and variety of the data.

In our work below several of the challenges mentioned above are address making use of so called artificial intelligence solutions, machine learning methodologies and other operational research and optimization techniques in order to optimize procedures and assist in the decision making processes.



Title:	*"Developments In Wind Power Forecast"*

Published in:	IO 2015 - XVII Congresso da Associação Portuguesa de Investigação Operacional (Portalegre, Portugal, 07 - 09 September 2015)	IO2015 XVII Congresso da APDIO
Authors:	Nuno Pinho da Silva, Luís Rosa, Rui Pestana	
Keywords:	system operation; integration of renewables; dynamic wind power forecast; forecast uncertainty	

Abstract:	Electricity generation from renewable sources is showing an increasing trend and plays a crucial role in the implementation of the strategic European energy targets. Wind generation is one well established case of electricity generation from renewable sources, where the wind kinetic energy is converted into electricity by the wind turbines; in Portugal, it accomplished 24% of the electricity consumption in 2014. To promote wind energy integration in the Portuguese electric system developed a wind power forecast tool to support decision-making in its control center. The work draws wind power forecasts from a self-adaptive ensemble of predictions. Wind power forecasts are weighted linear combinations of the ensemble elements. The weights of the combination change over time according to the minimization of the least squares error, thus providing the dynamic combination deterministic forecast. The deterministic forecast, or point forecast, provides the best indication available for the wind power production.

Title:	*"Improving Power Systems Operation in the Presence of RES – Application of Optimization Methods to Maximize Wind Power Integration"*

Published in:	IO 2015 - XVII Congresso da Associação Portuguesa de Investigação Operacional (Portalegre, Portugal, 07 - 09 September 2015)	IO2015 XVII Congresso da APDIO
Authors:	Rui Alves, Francisco Reis, Ricardo Pastor, Zutao Xiang, Shen Hong	
Keywords:	power systems; renewable energy sources; key cutting algorithm; swarm algorithms; decision making support	

Abstract:	In this paper, the problem of optimizing wind power penetration into energy systems while respecting technical constraints is presented. Due to its combinatorial nature this work makes use of heuristic methods to provide near-optimal solutions, allowing system operators to take best and timely decisions for day-ahead operational purposes. Two approaches are taken based on Key Cutting and Swarm Algorithms. Major findings demonstrate the capability of applied methods to solve the ad-dressed problem. Numerical case-studies highlight the applicability of the devel-oped tools to real-world power systems.

Title:	*"Probabilistic Dimensioning of Tertiary Control Reserve Driven by the Intermittency of Renewable Generation in Portugal"*

Published in:	Cigré Session 46 (2016) (Paris, France, 22 – 26 AUGUST 2016)	cigre
Authors:	Nuno Pinho da Silva, Rui Pestana	
Keywords:	operations planning; load-frequency control; tertiary control reserve; renewable generation; nonparametric probabilistic forecast	

Abstract:	This research work addresses the problem of dimensioning tertiary load-frequency control reserve. The proposed methodology exploits a nonparametric probabilistic framework to predict, separately, the probability distribution of the positive and negative imbalances. The proposed nonparametric probabilistic forecast leverages the linear interpolation of the sample order statistics to provide an efficient and distribution-free method for quantile regression. There are three key features in this approach: the first is the ability to compute the minimum sample size as a function of the required nominal coverage rate. The second is that the estimation error decreases with the second order of the sample size. The third is the computational efficiency of linear interpolation methods. To assess the technic and economic performance of the dimensioned reserves, this work introduces the reserve coverage error. For each direction, it evaluates the method's ability to provide sufficient active power together with its ability to provide the lowest possible requirements when compared to the mobilized reserves.

Title:	*"Big Data In Power Systems - Leveraging Grid Optimization And Wave Energy Integration"*

Published in:	23rd ICE/IEEE ITMC Conference (Madeira Island, Portugal, 27-29 June 2017)	International Conference on Engineering, Technology and Innovation
Authors:	Nuno Amaro, João Murta Pina	
Keywords:	big data; real-time systems; data privacy; business; oceans; power system dynamics	

Abstract:	Power systems have been through different challenges and technological innovations in the last years and are rapidly evolving into digital systems through the deployment of the smart grids concept. Producing large amounts of data, power systems can benefit from the application of big data analytics which can help leveraging the optimization processes going on in power grids nowadays. The whole value of chain of electric power can benefit from the application of big data techniques. This paper presents a short overview of possible applications and challenges that still need to be considered for this synergy to grow. Under the framework of an H2020 funded project named BigDataOcean, a case study will be described, showing how a data-driven approach can foster the development of offshore renewable sources using the example of wave energy.

Title:	*"A Methodology For Assessing The Impact Of The Interannual Variability of Wave Energy Resource On Electrical Energy Conversion"*

Published in:	SEST 2018 Conference (Seville, Spain, 10-12 September 2018)
Authors:	Nuno Amaro, Rui Amaral Lopes, et al.
Keywords:	big data; sea state; matrix converters; biological system modeling; energy conversion; industries; energy resources

Abstract:	This paper presents a methodology to assess the wave energy potential and the impact of inter-annual variability of the resource in overall energy production. This methodology was developed in the scope of a running H2020 project named Big-DataOcean, which aims to create a data repository and service marketplace for the maritime sector. The methodology is applied considering data from two different locations in the Portuguese coast for the years of2016 and 2017. Additionally, two wave energy converters are also used to verify the impact of inter-annual variability in the energy production through well-established KPI's.

Title:	*"Energy Forecasting Using An Ensemble Of Machine Learning Methods Trained Only With Electricity Data"*

Published in:	2020 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe) (Virtual, 26-28 October 2020)
Authors:	Gonçalo Luís, João Esteves, Nuno Pinho da Silva
Keywords:	load forecasting; PV forecasting; machine learning; energy big data

Abstract:	This work presents case studies on forecasting PV power production and electricity demand in Portugal. We study an ensemble of different machine learning methods to exploit the growing collection of energy supply and demand records. The ensemble uses only electricity data to forecast, since this data is available online for any forecasting horizon. The ensemble relies on offline training and online forecasting, by applying the most recent power measurements to trained models. The different machine learning methods perform different non-linear transformations to the same electricity data, thus introducing diversity in the ensemble. To assess the forecasting performance of this system, we consider two forecasting horizons relevant to the Internal Electricity Market, namely 36 hours ahead, relevant to the single day ahead coupling, and 2 hours ahead, relevant to the single intraday coupling. The forecasting performance using only electricity data compares gracefully with the state-of-the-art and improves the reference accuracy in our case studies. Since the ensemble relies only on energy data, the results show that machine-learning methods are useful to exploit energy big data towards efficient energy forecasting systems.

Title:	*"A Comparison of Deep Learning Architectures for Short-Term Load Forecasting: A Case Study on the Portuguese Load Amidst the Covid-19 Pandemic"*

Published in:	IISA 2022 - Thirteen IEEE International Conference on Information, Intelligence, Systems and Applications (Corfu, Greece, 18-20 July 2022)
Authors:	Francisco Silva, Nuno Amaro, et al.
Keywords:	COVID-19; deep learning; N-BEATS; short-term load forecasting

Abstract:	In smart power grids, short-term load forecasting (STLF) is crucial for energy companies as it contributes to the optimization of the reliability, emissions and cost of the power grid while it enables their participation in the energy markets. Unlike traditional time series forecasting, STLF is a more challenging task, due to the complex demand of active and reactive power from multiple types of electrical loads. Moreover, numerous exogenous variables such as the weather conditions, energy prices, seasonal factors and special events and occasions affect the behaviour of time series and require the modeler's attention and potentially custom handling depending on the employed technique. This work conducts a comparative study of Deep Learning techniques, namely Neural Basis Expansion Analysis Time Series Forecasting (N-BEATS), Long Short-Term Memory (LSTM), and Temporal Convolutional Networks (TCN) also taking into consideration the effect of the COVID-19 pandemic on their forecasting performance.

Title:	*"Circuit Breaker condition based maintenance using Advanced Fault Detection and Analysis on COMTRADE Event Data"*

Published in:	15th APCA International Conference on Automatic Control and Soft Computing (CONTROLO 2022) (Caparica, Portugal, 6-8 July 2022)
Authors:	Francisco Silva, Nuno Amaro.
Keywords:	fault detection; fault analysis; circuit breakers

Abstract:	A systematic and systemic analysis of historical data in power systems can contribute to the creation of condition based monitoring solutions for critical assets as circuit breakers. This work presents a methodology that automatic processes event-based data in COMTRADE format to obtain relevant metrics used in asset management. It considers the data processing, fault detection, classification and analysis stages at both, device and system level to aggregate and provide relevant metrics to end users. The methodology is validated using a sub-set of real life COMTRADE files from faults that occurred in the Portuguese Transmission System, between the years 2011 and 2021. The outcomes of this validation step are herein presented as well.

Title:	*"Transmission Tower Classification Using Point Cloud Similarity"*

Published in:	15th APCA International Conference on Automatic Control and Soft Computing (CONTROLO 2022) (Caparica, Portugal, 6-8 July 2022)	
Authors:	Francisco Silva, Nuno Amaro.	
Keywords:	point cloud; transmission system; classification	

Abstract:	Right-of-Way managers have increasingly used LiDAR inspections as an input to monitoring and maintenance activities of their infrastructures, making up a large percentage of the volume of data stored. Much of the shortcomings of this use revolve around the ability to accurately process data, classify elements and apply fitting monitoring strategies. This issue is raised by TSOs, when linking overhead line transmission tower scans to their respective models. In this sense, this work proposes a similarity based classification methodology to per-form this task, supported by traditional point cloud distance metrics, using a set of Base Reference Models (BRM) – models built on alignment algorithms ap-plied to pre-existent point clouds. This work tests this methodology for different sets of BRMs and point cloud distance metrics. We find that the effectiveness of this approach is highly related to the BRM resolution and to the distance metrics employed. For the use case at hand, the Chamfer distance similarity approached reached an accuracy as high as 89%.

Title:	*"Solving Issues Of The Distribution Network Of Harstad (Norway) In Real Time Using Machine Learning-Based Observability To Place Flexibility Orders"*

Published in:	CIRED 2023 International Conference and Exhibition on electricity distribution (Rome, Italy, 12-15 June 2023)	
Authors:	Nuno Pinho da Silva, Ângelo Casaleiro, et al.	

Abstract:	GIFT, a European Union H2020 project, has been the opportunity to design and implement a local flexibility market for its demonstration site on the island of Grytøya, part of the Harstad municipality located in Norwegian Arctic. The solution deployed uses machine learning based observability to update grid state estimation in real time and place flexibility orders. The project aims at solving intrinsic distribution network issues: congestion on critical assets and voltage excursions. This paper focuses on the integration of the observability element and the adjacent components with an emphasis on operational constraints.

Title:	*"Forecasting for Electricity Grid Planning: Current Challenges and Future Improvements"*

Published in:	CIRED 2023 International Conference and Exhibition on electricity distribution (Rome, Italy, 12-15 June 2023)	
Authors:	Ricardo Pastor, et al.	

Abstract:	Large changes in production and consumption of electricity poses a challenge for grid operators how to operate and plan the grid. Forecasting future demand and production is one way to reduce investment risks. This study investigates the challenges and opportunities of forecasting for grid planning and operation. A questionnaire towards network planners and operators finds that current forecasting methods mostly target load forecasting and new technology adoption. A majority of the respondents indicate that the uncertainty in their forecasts is high or very high and that confidence in the forecasts is only medium, and medium-low for long-term forecasts. Input data (amount, quality, handling etc) is seen as the largest challenge, while new, advanced models are seen as the biggest future improvement possibility.

Title:	*"All Models Are Wrong, But Some Are Useful: An Exploration of Confidence"*

Published in:	CIRED 2023 International Conference and Exhibition on electricity distribution (Rome, Italy, 12-15 June 2023)	
Authors:	Ricardo Pastor, et al.	

Abstract:	The subject of this paper is confidence in model outcomes used in the planning and operation of power grids. An important factor in the validity of models is that only a limited number of context variables can be taken into account, while at the same time the context in which we operate is changing rapidly and unexpectedly. Considering the quickly changing and complex context we operate in, the question arises how modelers and users of model outcomes deal with potentially massively changing conditions and input parameters in practice. This exploratory research used interviews to gain insight into this issue. The main outcomes are that modelling of current situation is observed as high, for short-term medium to high and long-term low to medium.

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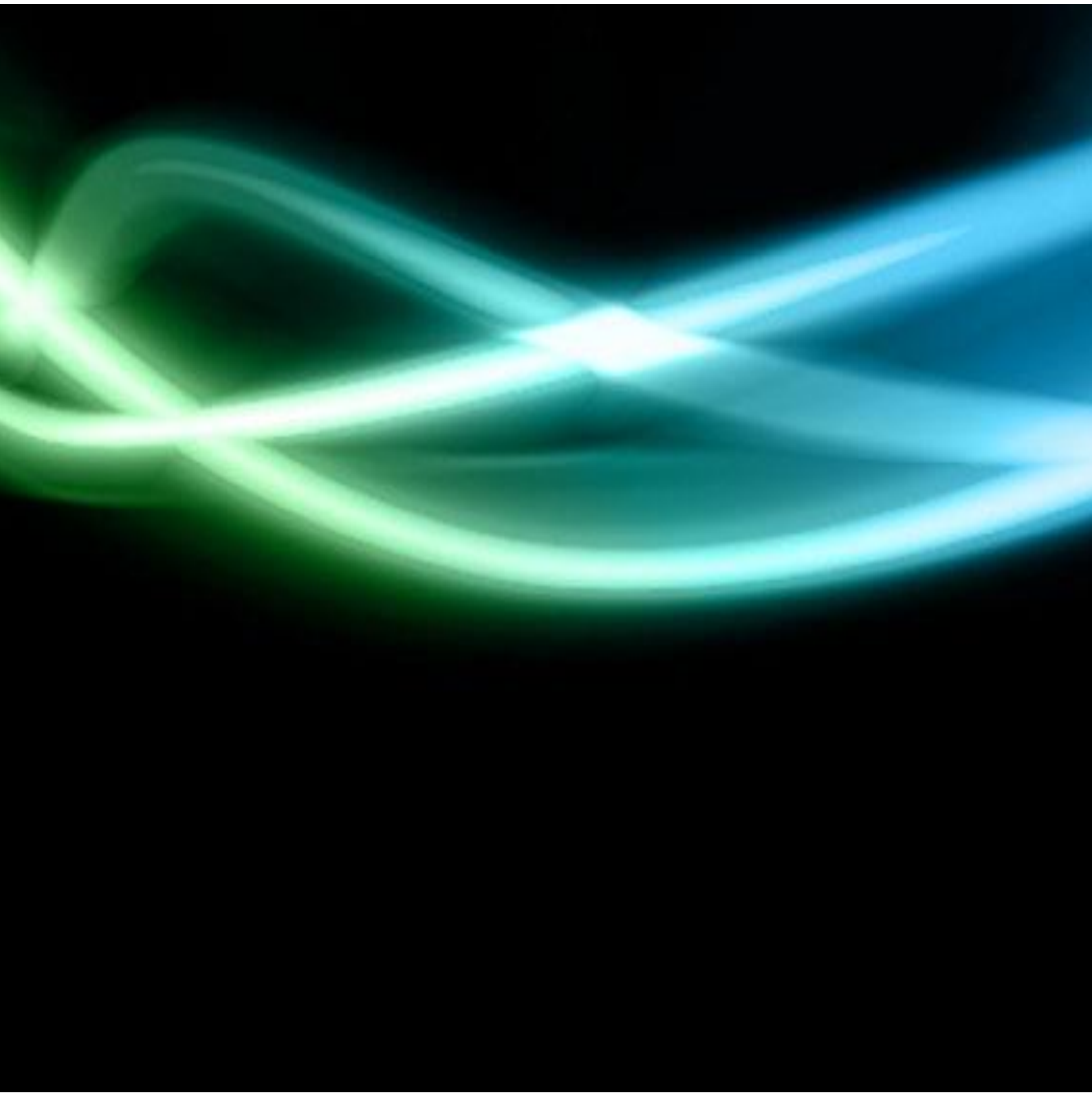

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