ISSN 2523-2517

Volume 9, Issue 21 — January — December — 2025

Journal Electrical Engineering

ECORFAN®

Journal Electrical Engineering, Volume 9, Issue 21: e2025921 January – December 2025, is a Continuous publication ECORFAN-Peru. La Raza Av. 1047 No. - Santa Ana, CuscoPeru. Postcode: 11500. WEB: www.ecorfan.org/republicofperu, revista@ecorfan.org. Editor in Chief: Quintanilla - Cóndor, Cerapio. PhD. ISSN: 2523-2517. Responsible for the last update of this issue of the ECORFAN Informatics Unit. Escamilla-Bouchán Imelda, Luna-Soto, Vladimir, updated December 30, 2025.

Journal Electrical Engineering

Definition of Journal

Scientific Objectives

Support the international scientific community in its written production Science, Technology and Innovation in the Field of Engineering and Technology, in Subdisciplines Electromagnetism, electrical distribution sources, electrical engineering innovation, signal amplification, electric motor design, material science in power plants, management and distribution of electrical energies.

ECORFAN-Mexico, S.C. is a Scientific and Technological Company in contribution to the Human Resource training focused on the continuity in the critical analysis of International Research and is attached to SECIHTI-RENIECYT number 1702902, its commitment is to disseminate research and contributions of the International Scientific Community, academic institutions, agencies and entities of the public and private sectors and contribute to the linking of researchers who carry out scientific activities, technological developments and training of specialized human resources with governments, companies and social organizations.

Encourage the interlocution of the International Scientific Community with other Study Centers in Mexico and abroad and promote a wide incorporation of academics, specialists and researchers to the publication in Science Structures of Autonomous Universities - State Public Universities - Federal IES - Polytechnic Universities - Technological Universities - Federal Technological Institutes - Normal Schools - Decentralized Technological Institutes - Intercultural Universities - S & T Councils - SECIHTI Research Centers.

Scope, Coverage and Audience

Journal Electrical Engineering is a Research Journal edited by ECORFAN-Mexico S.C in its Holding with repository in Republic of Peru, is a scientific publication arbitrated and indexed with semester periods. It supports a wide range of contents that are evaluated by academic peers by the Double-Blind method, around subjects related to the theory and practice of Electromagnetism, electrical distribution sources, electrical engineering innovation, signal amplification, electric motor design, material science in power plants, management and distribution of electrical energies with diverse approaches and perspectives , That contribute to the diffusion of the development of Science Technology and Innovation that allow the arguments related to the decision making and influence in the formulation of international policies in the Field of Engineering and Technology. The editorial horizon of ECORFAN-Mexico® extends beyond the academy and integrates other segments of research and analysis outside the scope, as long as they meet the requirements of rigorous argumentative and scientific, as well as addressing issues of general and current interest of the International Scientific Society.

Assignment of Rights

The sending of an Article to Journal Electrical Engineering emanates the commitment of the author not to submit it simultaneously to the consideration of other series publications for it must complement the Originality Format for its Article.

The authors sign the Authorization Format for their Article to be disseminated by means that ECORFAN-Mexico, S.C. In its Holding Republic of Peru considers pertinent for disclosure and diffusion of its Article its Rights of Work.

Declaration of Authorship

Indicate the Name of Author and Coauthors at most in the participation of the Article and indicate in extensive the Institutional Affiliation indicating the Department.

Identify the Name of Author and Coauthors at most with the CVU Scholarship Number-PNPC or SNI-SECIHTI- Indicating the Researcher Level and their Google Scholar Profile to verify their Citation Level and H index.

Identify the Name of Author and Coauthors at most in the Science and Technology Profiles widely accepted by the International Scientific Community ORC ID - Researcher ID Thomson - arXiv Author ID - PubMed Author ID - Open ID respectively.

Indicate the contact for correspondence to the Author [Mail and Telephone] and indicate the Researcher who contributes as the first Author of the Article.

Plagiarism Detection

All Articles will be tested by plagiarism software PLAGSCAN if a plagiarism level is detected Positive will not be sent to arbitration and will be rescinded of the reception of the Article notifying the Authors responsible, claiming that academic plagiarism is criminalized in the Penal Code.

Arbitration Process

All Articles will be evaluated by academic peers by the Double-Blind method, the Arbitration Approval is a requirement for the Editorial Board to make a final decision that will be final in all cases. MARVID® is a derivative brand of ECORFAN® specialized in providing the expert evaluators all of them with Doctorate degree and distinction of International Researchers in the respective Councils of Science and Technology the counterpart of SECIHTI for the chapters of America-Europe-Asia- Africa and Oceania. The identification of the authorship should only appear on a first removable page, in order to ensure that the Arbitration process is anonymous and covers the following stages: Identification of the Research Journal with its author occupation rate - Identification of Authors and Coauthors - Detection of plagiarism PLAGSCAN - Review of Formats of Authorization and Originality-Allocation to the Editorial Board-Allocation of the pair of Expert Arbitrators-Notification of Arbitration -Declaration of observations to the Author-Verification of Article Modified for Editing-Publication.

Instructions for Scientific, Technological and Innovation Publication

Knowledge Area

The works must be unpublished and refer to topics of Electromagnetism, electrical distribution sources, electrical engineering innovation, signal amplification, electric motor design, material science in power plants, management and distribution of electrical energies and other topics related to Engineering and Technology.

Presentation of the content

As the first article we present, *Photovoltaic energy manager with battery storage system for water pumping in isolated system*, by González-Aguayo, Mauricio Iván, Pérez-Hernández, Gustavo and Arroyo-Rodríguez, Francisco José, with affiliation at the Tecnológico Nacional de México campus Cancún, as the next article we present, *Study of the discrete elements method in Lithium-ion batteries*, by Fernández-Gómez, Tomas, Fernández-Pérez, Vladimir Damian, Ramírez-Rodríguez, Ramón Rodolfo and Fernández-Pérez, Mitzy E, with adscription in the Tec. Nacional de México- Tecnológico de Orizaba, as next article we present, *Kalman Filter: Optimal estimation in electrical, mechanical, and digital systems*, by Medécigo-Cabriales, Felipe A., Alaffita-Hernández, Francisco Alejandro, Colorado-Garrido, Dario and Escobedo-Trujillo, Beatris Adriana, from the Universidad Veracruzana, as last article we present *Implementation of single-line diagrams for an electrical substation Ref*, by Rosas-Ortiz, Lenin Jacobo, Molina-García, Moises, Fuentes-Ramos, Francisco and Díaz-Cogco, Jonathan, with affiliation at the Tecnológico Nacional de México - Instituto Tecnológico Superior de Huatusco.

Content

Article	Page
Photovoltaic energy manager with battery storage system for water pumping in isolated system González-Aguayo, Mauricio Iván, Pérez-Hernández, Gustavo and Arroyo-Rodríguez, Francisco José *Tecnológico Nacional de México campus Cancún*	1-9
Study of the discrete elements method in Lithium-ion batteries Fernández-Gómez, Tomas, Fernández-Pérez, Vladimir Damian, Ramírez-Rodríguez, Ramón Rodolfo and Fernández-Pérez, Mitzy E *Tec. Nacional de México- Tecnológico de Orizaba*	1-7
Kalman Filter: Optimal estimation in electrical, mechanical, and digital systems Medécigo-Cabriales, Felipe A., Alaffita-Hernández, Francisco Alejandro, Colorado-Garrido, Dario and Escobedo-Trujillo, Beatris Adriana *Universidad Veracruzana*	1-8
Implementation of single-line diagrams for an electrical substation Ref Rosas-Ortiz, Lenin Jacobo, Molina-García, Moises, Fuentes-Ramos, Francisco and Díaz-Cogco, Jonathan *Tecnológico Nacional de México - Instituto Tecnológico Superior de Huatusco*	1-5

Journal Electrical Engineering 9[21]1-9: e1921109
Article

Photovoltaic energy manager with battery storage system for water pumping in isolated system

Gestor de energía fotovoltaica con sistema de almacenamiento en baterías para bombeo de agua en sistemas aislados

González-Aguayo, Mauricio Iván * [a], Pérez-Hernández, Gustavo [b] and Arroyo-Rodríguez, Francisco José [c]

[a] ROR Tecnológico Nacional de México campus Cancún • MGU-9164-2025 • 0009-0005-0401-7832 • 1244906
[b] ROR Tecnológico Nacional de México campus Cancún • LLM-5096-2024 • 0000-0003-2767-4518 • 773391
[c] ROR Tecnológico Nacional de México campus Cancún • MBU-9381-2025 • 0000-0002-4073-5867 • 300913

Classification:

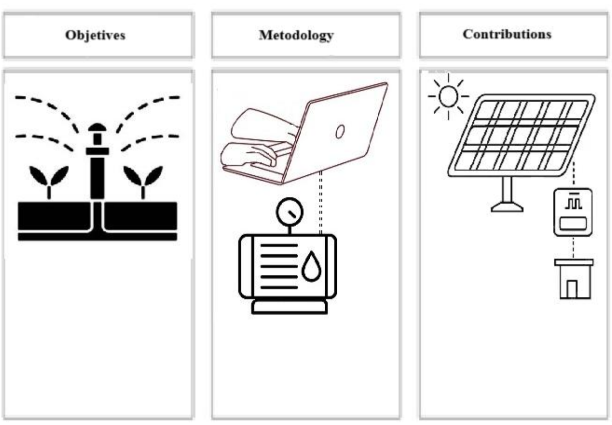
Area: Engineering
Field: Technological sciences
Discipline: Energy technology
Subdiscipline: Unconventional sources of energy

https://doi.org/10.35429/JEE.2025.9.21.1.1.9
History of the article:
Received: January 28, 2025
Accepted: March 30, 2025

* ✉ [francisco.ar@cancun.tecnm.mx]

Abstract

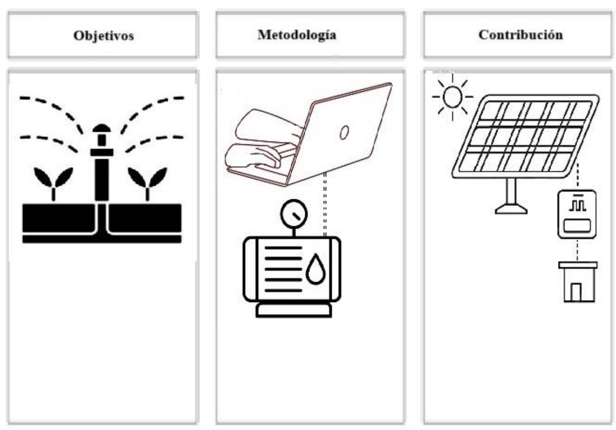
This paper presents a study carried out in a rural town in the Maya area of Quintana Roo, Mexico, where a photovoltaic system isolated from the electrical grid was installed, which supplies irrigation equipment to be used by an agricultural community. The ideal energy manager for the working conditions was analyzed and a device was designed according to the characteristics of the region. It was simulated with the help of an algorithm in order to improve the efficiency with respect to the energy obtained and the demand of the system during its operation in real conditions. It concludes by providing some recommendations for the operation of the system.



Energy manager, Photovoltaic system, Battery storage, Sustainable agriculture

Resumen

Este trabajo presenta un estudio realizado en un poblado rural de la zona Maya de Quintana Roo, México donde se instaló un sistema fotovoltaico aislado de la red eléctrica, que alimenta un equipo de riego para emplearse por una comunidad agrícola. Se analizó cual es gestor de energía idóneo para las condiciones de trabajo y se diseñó un equipo de acuerdo con las características de la región, se simuló con ayuda de un algoritmo con el fin de mejorar la eficiencia respecto a la energía obtenida y demanda del sistema durante su funcionamiento en condiciones reales. Se concluye proporcionando algunas recomendaciones para la operación del sistema.



Gestor de energía, Sistema fotovoltaico, Almacenamiento en baterías, Agricultura sustentable.

Area: Advocacy and attention to national problems

Citation: González-Aguayo, Mauricio Iván, Pérez-Hernández, Gustavo and Arroyo-Rodríguez, Francisco José. [2025]. Photovoltaic energy manager with battery storage system for water pumping in isolated system. Journal Electrical Engineering. 9[21]1-9: e1921109.

Journal Electrical Engineering 9[21]1-9: e1921109
Article

Introduction

Photovoltaic systems, installed in remote areas with or without energy storage for water supply, are gaining prominence in the market. They are increasingly replacing diesel generators, particularly when prices are favorable for local communities, and providing energy access to distant, inhabited rural areas [Grupo NAP, 2010]

The agricultural sector is facing so many issues and challenges related to feeding security, resources administration, and some climate change effects reduction.

One strategy for addressing the challenges in the agricultural sector is to leverage renewable energies, such as solar energy. Photovoltaic [PV] systems have experienced exponential growth over the past few decades, driven by technological advancements and cost reductions. This growth highlights the potential of PV systems to provide a reliable and sustainable energy supply that meets the needs of the agricultural sector. However, the variability in PV energy production poses a significant challenge, particularly in ensuring a consistent energy supply for various agricultural applications, including irrigation, machinery operation, cleaning, and storage [Byrne et al., 2017; Majeed et al., 2023]

To enhance efficiency and energy management, we recognize the importance of optimizing the exploitation of solar energy, which requires harnessing energy directly from the sun. This optimization is crucial to overcome the challenges associated with solar energy production and unlock its full potential.

Numerous studies have investigated various control strategies and PV management approaches, as well as agricultural wind applications, such as water pumping [Poompavai & Kowsalya, 2019]. Additionally, the strategic implementation of energy storage systems using batteries has yielded promising results, enabling the provision of a continuous and uninterrupted electricity supply from solar energy. This study aims to integrate the findings and insights from previous investigations to develop a tailored algorithm for a photovoltaic energy system, specifically designed for agricultural applications and incorporating a battery supply design.

We have documented several case studies highlighting the economic and social impacts of photovoltaic energy in agriculture, particularly in the context of high-efficiency irrigation systems and its potential as an alternative energy source for agricultural energy management.

Methods and material

Irradiance data, as depicted in Figure 2, were obtained from the National Meteorological System of CONAGUA using the EMAS Nicolas Bravo station [Figure 1]. The station's coordinates are 18.45961111°N latitude, -88.93251944°W longitude, and 105 meters above sea level. These data were used to determine electric power production using a mathematical model for photovoltaic [PV] systems.

Box 1

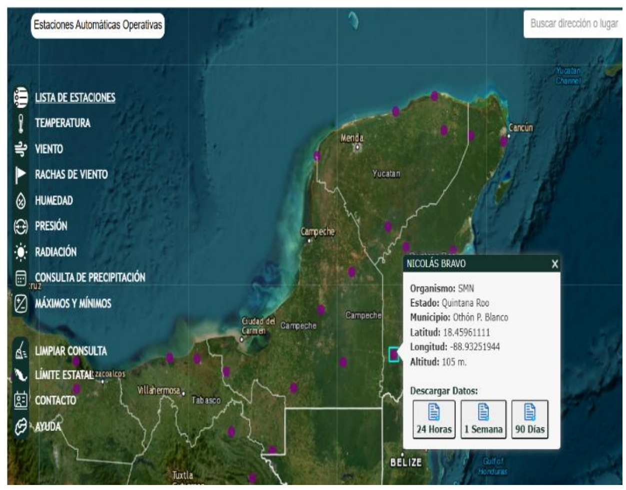


Figura 1

Location of the Nicolás Bravo Meteorological Station

Source: Author's own elaboration

A pumping operating system's curve graph was utilized to determine the required electric charge. Additionally, based on user demand data collected and applied in this study, we defined the system's behavior to accurately reflect real-world operating conditions.

The development of this energy management algorithm, along with its simulation validation, was conducted using Matlab software. This approach enabled us to obtain detailed profiles and characteristics of energy demand and generation.

ISSN: 2523-2517
RENIECYT: 1702902

González-Aguayo, Mauricio Iván, Pérez-Hernández, Gustavo and Arroyo-Rodríguez, Francisco José. [2025]. Photovoltaic energy manager with battery storage system for water pumping in isolated system. Journal Electrical Engineering. 9[21]1-9: e1921109.
https://doi.org/10.35429/JEE.2025.9.21.1.1.9

Furthermore, we were able to observe how the system responds to various operating conditions, including different charging scenarios and solar irradiance levels, which impact the energy manager and battery storage system. This research is currently theoretical, but our ultimate goal is to implement and test the algorithm in a real-world setting.

The efficiency of photovoltaic [PV] panels varies across different zones due to fluctuations in irradiance and temperature throughout the year's seasons [Kerdphol et al., 2016]. To measure irradiance, a silicon pyranometer cell can be installed directly into the system, providing an average annual measurement value. This value is typically represented on an insolation graph and expressed in units of W/m².

The impact of temperature on photovoltaic performance is quantified using the temperature coefficient, K_CO T_a. By considering the inverter efficiency [η_inv] and the panel's relative efficiency [η_rel], the photovoltaic power output can be expressed as a function of temperature and irradiance:

$$P_{pf} = N_{pf} P_{rat\eta pf} (G(t)/G_o)\big(1 - K_{CO}(T_a - 25°)\big)\eta_{inv}\eta_{rel}$$

Box 2

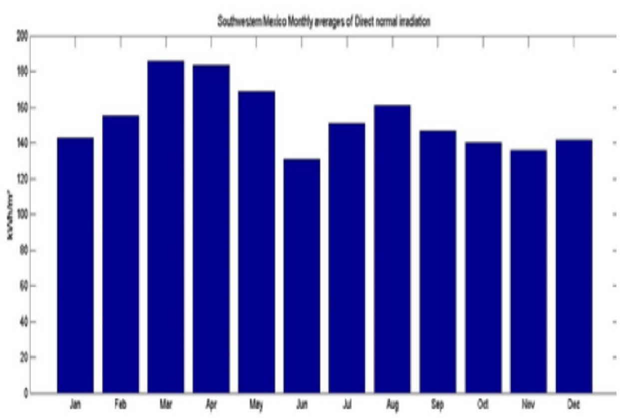


Figura 2

Solar irradiation for southeastern Mexico

Source: Author's own elaboration

The proposed SPV [Solar Photovoltaic System] does not employ an inverter, so η_inv is cancelled out in the equation. N_pf represents the number of Photovoltaic Panels [PP], P_ratηpf is the nominal power of the PF expressed in W, G[t] is the solar irradiance expressed in W/m², Go is the standard irradiance of the photovoltaic panel expressed as 1 kW/m².

Here, K_CO represents the temperature coefficient at maximum power of the PP, T_a is the ambient temperature, and η_rel is the relative efficiency of the PP.

PV components

Photovoltaic [PV] panels are devices specifically designed and manufactured to convert sunlight into electricity. These panels are constructed from materials that harness the photovoltaic effect, where the absorption of photons from sunlight releases electrons, generating electrical energy [Hernández-Callejo et al., 2019]

The energy generated by photovoltaic [PV] systems is directly influenced by three key factors: the intensity of solar radiation, efficiency, and environmental conditions. The nominal power output of a PV system is typically specified in watts [Wp], which represents the maximum energy production under optimal conditions [Verma et al., 2020].

The proposed PV system consists of six 280 W_p photovoltaic modules connected in series. Each module operates with an open-circuit voltage of 39V and a short-circuit current of 9.25A. This configuration supplies power to a high-efficiency submersible pump with a power rating of 1.6 kWpico.

We assessed the system's energy consumption by providing a continuous current. The system is designed to irrigate a specific area for one hour per day. Given the absence of a controller or additional converter, the system configuration was simplified. Moreover, the system lacks an additional energy conversion setup or any other optimization feature, resulting in a relatively low-efficiency setup.

Submersible pumps for PV applications typically employ continuous current motors due to their desirable characteristics and efficiency. These motors offer a significant advantage when operating directly with the continuous current output generated by the PV system, thereby eliminating the need for inverters or additional controllers. This characteristic simplifies the system configuration, leading to improved overall efficiency and reduced costs. Notably, continuous current motors exhibit high efficiency in pumping applications, providing a constant water flow that is reliable for crop irrigation [Verma et al., 2020].

ISSN: 2523-2517
RENIECYT: 1702902

Continuous current motors without carbon brushes or commutators offer a viable alternative to induction motors, boasting improved efficiency and reliability. The absence of brushes reduces friction, sparking, and wear, resulting in increased efficiency and a longer lifespan. Additionally, these motors feature a high starting torque, which is essential for ensuring reliable startup under variable solar irradiance conditions. These characteristics make them a promising and effective option for pumping applications powered by photovoltaic solar energy, contributing to the development of sustainable pumping systems.

Energy storage solutions, such as batteries, come in various technologies. Traditional lead-acid batteries are common, while lithium-based batteries, specifically $LiFePO_4$ types, offer extended lifespans and reduced long-term costs due to fewer replacements. Moreover, lithium [Li] batteries exhibit superior charging and discharging performance, enabling better management of energy harvested from photovoltaic [PV] systems. As the cost of lithium batteries is expected to decrease over time, their economic viability compared to lead-acid batteries are increasing [Dufo-López et al., 2021].

The implementation of lithium-ion [Li-ion] batteries enhances the overall efficiency of the system. Furthermore, integrating a Li-ion battery into an energy management system that is directly connected to the grid can optimize efficiency, charging management, and stabilization of electrical network consumption [Kim et al., 2015].

A comparative analysis of photovoltaic [PV] systems using lithium-ion batteries versus lead-acid batteries reveals that the former require approximately 40% fewer units. This is attributed to the superior reliability, efficiency, and cost-effectiveness of lithium-ion batteries.

Furthermore, lithium-ion batteries exhibit better performance characteristics, including terminal voltage, charging status, current, and lifespan, compared to lead-acid technology. Notably, they demonstrate a better discharging response, underscoring their enhanced performance [Kebede et al., 2021].

Energy Management System [EMS]: Also known by its English acronym, this system analyzes, controls, and monitors energy consumption, charging, and discharging within a specific area. The primary objective of the EMS is to ensure efficient and sustainable operation during the use of the Solar Photovoltaic System [SPV].

There are numerous possibilities for harnessing renewable resources, such as wind currents and solar radiation. However, a common requirement among these options is the need for energy storage systems to facilitate the availability of electricity for end-users at the moment it is required. To achieve this, a reliable load management system is essential.

This system enables the storage of excess energy generated during periods of high solar irradiance, allowing it to be utilized during times of increased demand or low solar radiation [Nge et al., 2019]. Therefore, the Energy Management System [EMS] must incorporate a program that intelligently coordinates energy supply and demand in real-time. To effectively implement these systems, accurate measurements of solar irradiance and precise estimates of energy consumption are essential [Iris, Ç., & Lam, J., 2019].

Results and Discussion

The proposed Solar Photovoltaic System [SPV] for irrigation water pumping in agricultural areas exhibits low energy efficiency due to the lack of an energy storage system and an optimal energy management system. To simulate the system, a SPV consisting of 6 photovoltaic [PV] panels of 280 W each, connected in series, was proposed to power an irrigation pump with an operational capacity ranging from 400 to 1600 W, without an inverter-controller. According to the irrigation system users, the system operates three days a week, for one hour each day.

Figure 3 illustrates the operation of the proposed SPV. The top portion of the graph shows energy generation over a four-day period, while the bottom portion reveals that the energy consumption of the pump on irrigation days only utilizes 18% of the generated energy. A significant energy loss is observed during the depicted period, whereas on non-irrigation days, the entire energy generated remains unused.

ISSN: 2523-2517
RENIECYT: 1702902

González-Aguayo, Mauricio Iván, Pérez-Hernández, Gustavo and Arroyo-Rodríguez, Francisco José. [2025]. Photovoltaic energy manager with battery storage system for water pumping in isolated system. Journal Electrical Engineering. 9[21]1-9: e1921109.
https://doi.org/10.35429/JEE.2025.9.21.1.1.9

The absence of an energy storage system [batteries] and energy management system restricts agricultural operations and hinders sustainable development in these communities [Trommsdorff et al., 2021; Agrawal, & Jain, 2019]. Therefore, it is crucial to develop a methodology for energy storage and management to maximize the utilization of energy supplied by the SPV, and its application in agricultural areas.

This not only enhances the quality of work and increases the value of production but also mitigates the environmental impact associated with reliance on conventional energy sources [Peng et al., 2013].

Box 3

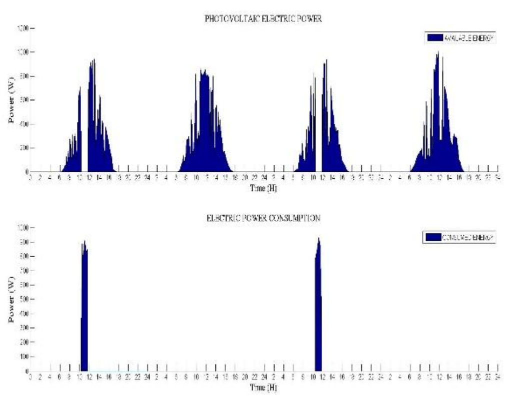


Figura 3

a] Energy generated by the SFV in 4 days.
b] Consumption of the installed pump for 4 days.

Source: Author's own elaboration

Battery Energy Storage Management System [BMS]

Batteries are the most widely used energy storage technology, thanks to advances in technology, ease of installation, and design [Akinyele, et al., 2017]. However, a crucial element for any energy storage method is the ability to monitor, control, and optimize performance in one or multiple batteries, as well as disconnect the SPV module in case of unusual conditions. This ensures reliable and efficient operation of the energy storage system.

The Battery Management System [BMS] plays a crucial role in optimizing battery performance, ensuring safe and reliable operation of the Solar Photovoltaic System [SPV] [Gabbar et al., 2021].

A dual-battery storage model is proposed to enhance lifespan, providing continuity in energy supply and introducing a novel concept for storage systems [Thurai et al., 2022]. proposal involves utilizing two batteries to achieve constant energy utilization. This design incorporates a management system that enables the administration of energy delivery at all times, as well as monitoring, controlling the charging and discharging of batteries, and managing the supply and consumption of energy provided by the SPV. Additionally, the system allows for direct energy supply to the pump when necessary.

Figure 4 illustrates a simulation using a single battery to regulate its charging and discharging, prioritizing direct consumption and giving precedence to the irrigation pump used in agricultural applications.

Box 4

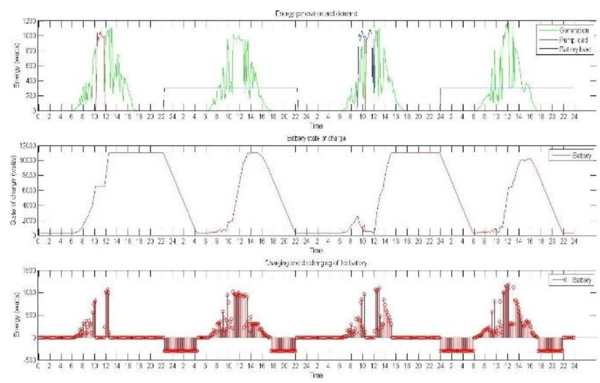


Figura 4

a] Daily PV generation, pump demand, and energy stored in the battery.
b] Battery state of charge, subject to charging and discharging, with available energy and proposed demand.
c] Input and output powers of the battery.

Source: Author's own elaboration

Proposed Energy Manager for Isolated SPV Systems with Agricultural Applications and Battery Storage: The algorithm enables the direct utilization of generated energy to power the submersible pump, while the energy stored in the batteries can be supplied to meet additional demand.

Figure 5 illustrates the operational flow diagram of the battery and proposed energy manager, outlining the sequential steps and decision-making processes involved in managing energy storage and distribution.

ISSN: 2523-2517
RENIECYT: 1702902

González-Aguayo, Mauricio Iván, Pérez-Hernández, Gustavo and Arroyo-Rodríguez, Francisco José. [2025]. Photovoltaic energy manager with battery storage system for water pumping in isolated system. Journal Electrical Engineering. 9[21]1-9: e1921109.
https://doi.org/10.35429/JEE.2025.9.21.1.1.9

Box 5

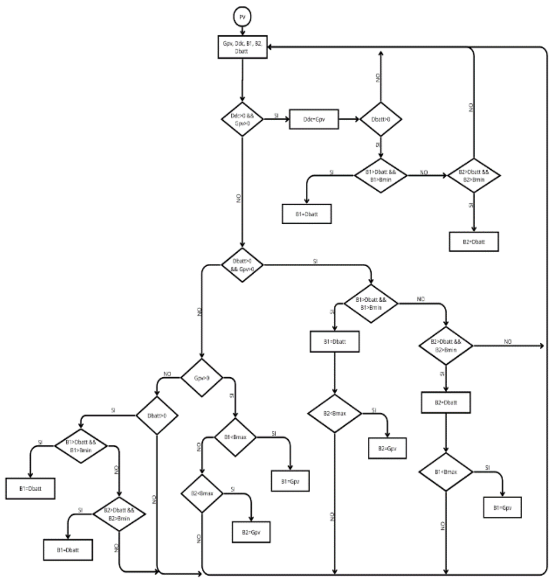


Figura 5

Proposed flow diagram for the energy manager.

Source: Author's own elaboration

Figure 5 illustrates the operation of the energy manager, which plays a crucial role in coordinating the efficient generation, storage, and distribution of energy in real-time, thereby ensuring optimal energy utilization.

This is achieved through continuous monitoring of battery charge levels [B1, B2], photovoltaic generation [Gpv], and demand from the pumping system [Ddc] and connected battery [Dbatt]. Once the management algorithm is activated, it checks if energy is required to directly supply power to the pump, utilizing the entire SPV generation to meet demand. Otherwise, it determines if excess energy is available to charge the batteries.

Various scenarios were simulated in the code for the charge-discharge control system of the batteries. This allows one battery to supply energy while the other can charge, providing a constant energy backup. If a battery has sufficient energy to handle an additional load from the submersible pump, the manager will connect the load to the available battery and direct the generation towards the battery that requires recharging.

This behavior enables maximum energy utilization without disrupting daily irrigation routines. The system leverages the storage and/or generation capabilities of the SPV as independent energy sources, which can satisfy separate demands in a coordinated and consistent manner.

Discussion

A simulation of the proposed manager was performed using Matlab software, incorporating real-time generation and demand data from the SPV in agricultural applications. This included a proposed energy demand for the storage system [batteries], aiming to demonstrate the manager's functionality and validate its performance under realistic operating conditions.

Figure 6 illustrates the primary behavior of the manager, which is to prioritize the demand of agricultural operations. Upon detecting a direct demand, such as the water pump in the case study, all energy generated by the SPV is supplied to meet this demand, allowing the current system behavior to remain unaffected. However, in the absence of demand, the generated energy is redirected to charge the batteries, optimizing energy utilization and storage.

In this scenario, the battery capacity was intentionally oversized for illustrative purposes. Observing the curves in Figure [6.c], a null behavior is noted, indicating no charging peaks in the batteries. This is attributed to the fact that between 10-12 hours, the system users operate the irrigation equipment, redirecting the available energy intended for battery charging to the irrigation system instead. Consequently, this enables users to maintain normal control over their sprinkler activities.

Box 6

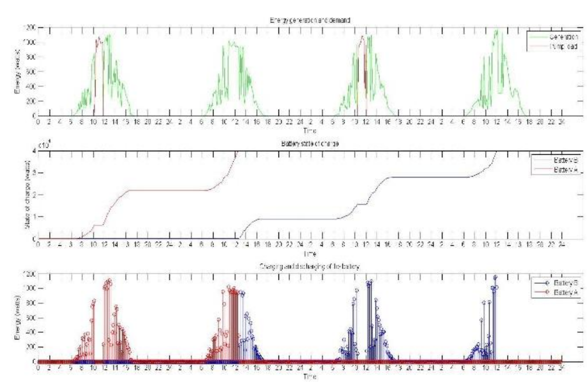


Figura 6

a] Photovoltaic energy generated and pump demand.
b] Charge level in the battery storage system.
c] Real-time power supplied to the batteries.

Source: Author's own elaboration

Figure 7 illustrates the behavior of the management system, with an additional demand directed towards the proposed battery system.

ISSN: 2523-2517
RENIECYT: 1702902

The manager takes real-time readings, considering the SPV generation, energy demand [in this case, used for water extraction and pumping in agricultural applications], battery charge condition, available charging time, and demand directly connected to the batteries.

The operation of the management system utilizes these readings to control the energy flow in the SPV, verifying whether generation is available and if there are any additional demands to be met, thereby ensuring optimal energy allocation and utilization.

The available energy is stored in the battery with the lowest charge, achieved by comparing the states of both batteries. The manager continues to charge the batteries until they reach maximum capacity. To enhance their lifespan, the manager limits charging and discharging within the minimum and maximum capacity thresholds specified by the batteries' design characteristics.

To illustrate the manager's functionality, a direct current demand was connected to the batteries at various time intervals. The simulation demonstrated that upon detecting the use of the pumping system, the manager limits battery charging and prioritizes the application, directing the generated energy towards the pump. This is evident in the 10–12-hour intervals in the graph shown in Figure 7.c], where the manager adapts energy allocation to meet the demand of the pumping system.

In the third curve of the same graph, Figure 7.c], it can be observed that the charging interaction ceases, yet energy supply from the battery array to an independent demand, separate from the pump, continues uninterrupted. This allows the user to access the stored energy at any time without needing to interrupt the irrigation process, thereby ensuring a reliable and consistent energy supply.

In this application, energy is utilized directly for 2 hours a day, while the remaining time is dedicated to charging the storage system. This approach aims to create a system with enhanced energy autonomy, enabling it to operate independently for extended periods.

Box 7

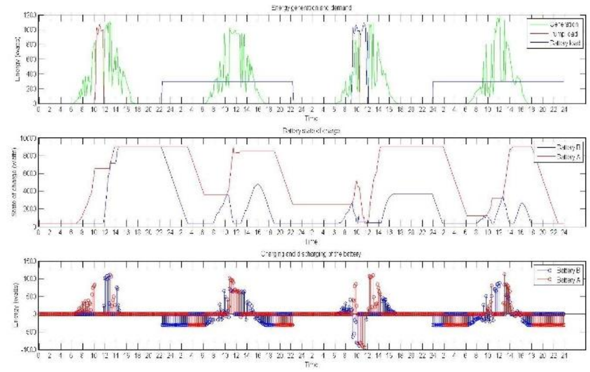


Figura 7

a] Energy generated by the photovoltaic system [SFV], pump demand, and battery charging status.
b] Battery charge-discharge cycles, including available energy and proposed demand.
c] Real-time input and output power flows to and from the batteries.

Source: Author's own elaboration

Conclussions

The results from the energy manager simulations validate that the behavior is suitable for SPV systems in remote installations. Furthermore, this type of simulation can be employed to dimension each component of the system prior to installation, helping to optimize energy utilization and ensuring that it aligns with the generated capacity, thereby maximizing efficiency and performance.

This management system can be utilized to detect various charge-discharge states and prevent future issues, such as periods of high demand exceeding generation, or low-consumption cycles resulting in unutilized energy, as well as unnecessary charging and discharging of the storage system. By optimizing energy allocation and storage, the system can improve overall efficiency, reduce energy waste, and prolong the lifespan of its compo ents.

This information enables users to make optimal use of energy, as well as transfer non-time-sensitive loads and adjust or schedule them flexibly to capitalize on periods of high energy generation. By doing so, users can maximize their energy efficiency, reduce waste, and optimize their overall energy consumption.

The energy manager simulation provides valuable insights that can be used to identify optimal charge-discharge times, as well as predict the lifespan of batteries based on their cycle count.

González-Aguayo, Mauricio Iván, Pérez-Hernández, Gustavo and Arroyo-Rodríguez, Francisco José. [2025]. Photovoltaic energy manager with battery storage system for water pumping in isolated system. Journal Electrical Engineering. 9[21]1-9: e1921109.
https://doi.org/10.35429/JEE.2025.9.21.1.1.9

Furthermore, the simulation can be used to model various scenarios, offering tailored recommendations to maximize efficiency and prolong the lifespan of the batteries. This enables users to make informed decisions, optimize their energy storage systems, and reduce maintenance costs.

Future work can leverage the energy manager simulation to investigate the impact of connecting the SPV system directly to the power grid [in this case, Comisión Federal de Electricidad]. By analyzing the effects on grid frequency and voltage, it is possible to determine the optimal connection point and size for the SPV system, ensuring a stable and efficient integration with the existing power infrastructure.

Additionally, this approach can help reduce costs by optimizing the balance between energy generation, demand, storage, and grid transactions [i.e., buying and selling energy]. By doing so, it is also possible to minimize the system's impact on the grid, promoting a more efficient, resilient, and sustainable energy ecosystem.

Declarations

Conflict of Interest Declaration

The authors declare that they have no competing financial interests or personal relationships that could have influenced the development of this work.

Author Contributions

The contributions of each researcher to the development of this investigation are as follows:

González-Aguayo, Mauricio Iván: Contributed to the development of the algorithm, software simulations, and partially to the main idea of the work.

Pérez-Hernández, Gustavo: Provided the main idea of the work, method [algorithm], research technique, and photovoltaic model.

Arroyo-Rodríguez, Francisco José: Contributed graphical summaries, translated the work, and assisted with editing and redrafting the manuscript.

Data and Material Availability

The solar irradiance data used for simulations in the proposed photovoltaic system model were obtained from the National Meteorological System of CONAGUA, utilizing the EMAS Nicolás Bravo weather station.

https://smn.conagua.gob.mx/es/observando-el-tiempo/estaciones-meteorologicas-automaticas-ema-s

Acknowledgments of Funding

This research was supported by [SECIHTI]. The authors gratefully acknowledge the financial support provided, which enabled the completion of this study.

Abreviaciones

EMAS	Estaciones Meteorológicas Automáticas
EMS	Energy Management System
Li	Lithium
PS	Solar Panel
PV	Photovoltaic
SFV	Solar Photovoltaic System
SMS	Storage management system
W	Watts

References

Agrawal, S. & Jain, A. [2018]. Sustainable deployment of solar irrigation pumps: Key determinants and strategies. In Wiley Interdisciplinary Reviews: Energy and Environment. Vol. 8, Issue 2. John Wiley and Sons Ltd.

Akinyele, D., Belikov, J. & Levron, Y. [2017]. Battery storage technologies for electrical applications: Impact in stand-alone photovoltaic systems. In Energies [Vol. 10, Issue 11]. MDPI.

Dufo-López R, Cortés-Arcos T, Artal-Sevil J. & Bernal-Agustín J. [2021]. Comparison of Lead-Acid and Li-Ion Batteries Lifetime Prediction Models in Stand-Alone Photovoltaic Systems. Applied Sciences.; [Vol.11, pp. 1099-1120].

Belgacem, F., Mostefai, M., Miloud Y. et al. Brushless Direct Current Motor versus Induction Motor in Photovoltaic Pumping Application: A Comparative Study, 28 October 2022, PREPRINT [Version 1] available at Research Square

ISSN: 2523-2517
RENIECYT: 1702902

González-Aguayo, Mauricio Iván, Pérez-Hernández, Gustavo and Arroyo-Rodríguez, Francisco José. [2025]. Photovoltaic energy manager with battery storage system for water pumping in isolated system. Journal Electrical Engineering. 9[21]1-9: e1921109.
https://doi.org/10.35429/JEE.2025.9.21.1.1.9

Grupo NAP. Colegio Oficial de Ingenieros de Telecomunicaciones. [2010]. Energía Solar Fotovoltaica. Madrid.

Hernández-Callejo, L., Gallardo-Saavedra, S. & Alonso-Gómez, V. [2019]. A review of photovoltaic systems: Design, operation and maintenance. In Solar Energy [Vol. 188, pp. 426–440]. Elsevier Ltd.

Iris, C. & Lam, J. [2019]. A review of energy efficiency in ports: Operational strategies, technologies and energy management systems. In Renewable and Sustainable Energy Reviews [Vol. 112, pp. 170–182]. Elsevier Ltd. https://doi.org/10.1016/j.rser.2019.04.069.

Kebede, A., Coosemans, T., Messagie, M., Jemal, T., Behabtu, H., Van Mierlo, J. & Berecibar, M. [2021]. Techno-economic analysis of lithium-ion and lead-acid batteries in stationary energy storage application. Journal of Energy Storage, 40, 102748.

Peng, J., Lu, L. & Yang, H. [2013]. Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems. Renewable and Sustainable Energy Reviews, [Vol.19, pp. 255–274].

Raza, F., Tamoor, M., Miran, S., Arif, W., Kiren, T., Amjad, W., Hussain, M. & Lee, G. [2022]. The Socio-Economic Impact of Using Photovoltaic [PV] Energy for High-Efficiency Irrigation Systems: A Case Study. Energies, [Vol.15 pp. 3-15].

Trommsdorff, M., Kang, J., Reise, C., Schindele, S., Bopp, G., Ehmann, A., Weselek, A., Högy, P., & Obergfell, T. [2021]. Combining food and energy production: Design of an agrivoltaic system applied in arable and vegetable farming in Germany. Renewable and Sustainable Energy Reviews, 140.

Basics

Byrne, R., Nguyen, T., Copp, D., Chalamala, B. & Gyuk, I. [2017]. Energy Management and Optimization Methods for Grid Energy Storage Systems. IEEE Access, 6, pp.13231–13260.

Gabbar, H., Othman, A. & Abdussami, M. [2021]. Review of Battery Management Systems [BMS] Development and Industrial Standards. In Technologies [Vol. 9, Issue 2]. MDPI.

Kerdphol, T., Fuji, K., Mitani, Y., Watanabe, M. & Qudaih, Y. [2016]. Optimization of a battery energy storage system using particle swarm optimization for stand-alone microgrids. International Journal of Electrical Power & Energy Systems, 81[Vol. 81, pp. 32-39].

Majeed, Y., Khan, M., Waseem, M., Zahid, U., Mahmood, F., Majeed, F., Sultan, M. & Raza, A. [2023]. Renewable energy as an alternative source for energy management in agriculture. In Energy Reports [Vol. 10, pp. 344–359]. Elsevier Ltd

Nge, C., Ranaweera, I., Midtgård, O. & Norum, L. [2019]. A real-time energy management system for smart grid integrated photovoltaic generation with battery storage. Renewable Energy, [vol. 130, pp. 774–785]

Supports

Kim, S., Bae, S., Kang, Y. & Park, J. [2015]. Energy Management Based on the Photovoltaic HPCS With an Energy Storage Device. IEEE Transactions on Industrial Electronics. [Vol. 62, pp. 4608–4617].

Poompavai, T. & Kowsalya, M. [2019]. Control and energy management strategies applied for solar photovoltaic and wind energy fed water pumping system: A review. In Renewable and Sustainable Energy Reviews [Vol. 107, pp. 108–122]. Elsevier Ltd.

Thurai, V., Gorantla, S., Karunanidy, D., Dumka, A., Singh, R., Rashid, M., Albagory, Y. & Alshamrani, S. [2022]. Dual Battery Storage Technique for Remote, Location-Based Solar PV System and Standalone Applications. Energies, 15[8].

Verma, S., Mishra, S., Chowdhury, S., Gaur, A., Mohapatra, S., Soni, A., & Verma, P. [2020]. Solar PV powered water pumping system – A review. Materials Today: Proceedings, [Vol. 46, Part. 11,pp. 5601-5606], S2214785320371509.

ISSN: 2523-2517
RENIECYT: 1702902

Journal Electrical Engineering 9[21]1-7: e2921107
Article

Study of the discrete elements method in Lithium-ion batteries

Estudio del método de elementos discretos en baterías de iones de Litio

Fernández-Gómez, Tomas [a], Fernández-Pérez, Vladimir Damian * [b], Ramírez-Rodríguez, Ramón Rodolfo [c] and Fernández-Pérez, Mitzy E. [d]

[a] ROR Tec. Nacional de México- Tecnológico de Orizaba • RHX-9721-2024 • 0000-0002-0311-5001 • 65262
[b] ROR Tec. Nacional de México- Tecnológico de Orizaba • RHX-9778-2024 • 0000-0002-3790-9352 • 699327
[c] ROR Tec. Nacional de México- Tecnológico de Orizaba • KHY-0222-2024 • 0000-0002-2724-3358 • 1024679
[d] ROR Tec. Nacional de México- Tecnológico de Orizaba • KHY-0254-2024 • 0000-0002-1984-2537 • 1071465

Classification:

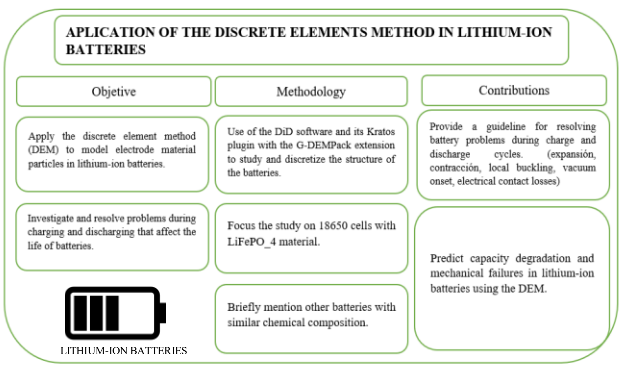
Area: Engineering
Field: Technological sciences
Discipline: Energy technology
Subdiscipline: Energy [physical]

https://doi.org/10.35429/JEE.2025.9.21.2.1.7
History of the article:
Received: March 19, 2025
Accepted: May 30, 2025

* ✉ [fernandez_gt@yahoo.com]

Abstract

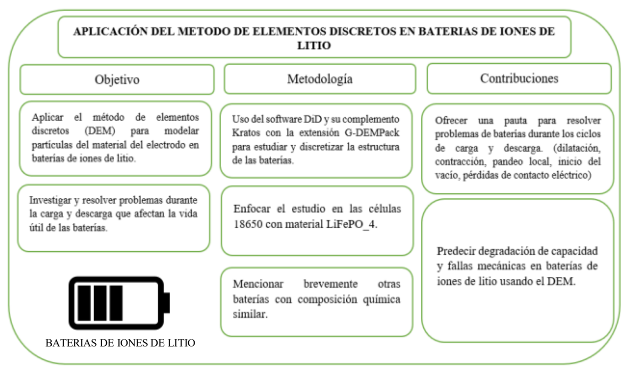
The purpose of this project is the application of the discrete element method [DEM] for the realization of a particle model based on the electrode material of the lithium-ion batteries in electric cars, trying to solve the main problems they present during charging and download since these directly affect the lifetime of the same



Electrode, Batteries, Electric Vehicle, Litio

Resumen

Este proyecto tiene como finalidad la aplicación del Método de Elementos Discretos [DEM] para la realización de un modelo de partículas basados en el material del electrodo de las baterías de iones de litio en autos eléctricos, intentando resolver los principales problemas que estos presentan durante la carga y la descarga ya que estos afectan directamente al tiempo de vida útil de las mismas.



Electrodo, Baterías, Vehículo Eléctrico, Lithium

Area: Dissemination of and universal access to science

Citation: Fernández-Gómez, Tomas, Fernández-Pérez, Vladimir Damian, Ramírez-Rodríguez, Ramón Rodolfo and Fernández-Pérez, Mitzy E. [2025]. Study of the discrete elements method in Lithium-ion batteries. Journal Electrical Engineering. 9[21]1-7: e2921107.

Introduction

The aim of this project is to apply the Discrete Element Method [DEM] to create a particle model based on the electrode material of lithium-ion batteries, trying to solve the main problems that these present during charging and discharging, as these directly affect the useful life of the batteries.

It was decided to focus the study on cells with 18650 dimensions as a graphic representation and composed of LiFePO_4, without forgetting that there is a great diversity of batteries with similar chemical composition of which a brief mention is made.

The GiD software and its complement Kratos with the G-DEMPack extension were used for the study and discretisation of the structure to be analysed.

This project is carried out in order to give a guideline for the resolution of the problem of the batteries with respect to the charge and discharge cycles, since these cause problems of physical and mechanical character among which we find: the dilation and contraction which generates a growth of the delamination, local buckling, beginning of the vacuum and loss of the electrical contact with the current collector.

The growing demand for electric vehicles is causing an intense development and research in the creation of more efficient batteries to drive these cars for longer distances, with more charge and a longer service life.

Thanks to this need arises the initiative to analyse the components of electric batteries and the problems they present over time, to know why the elements that store electrical energy gradually lose the quality of retaining enough energy for its proper functioning as well as transmitting it in a correct way to the parts of the car that require it.

- Electric battery

A battery is a device capable of storing energy in electrochemical form. There are two types: primary batteries and secondary batteries.
Primary batteries are characterised by the fact that the conversion of chemical energy to chemical to electrical energy is irreversible, i.e. after the battery has been completely discharged it cannot be recharged.

Secondary batteries: better known as rechargeable batteries. These, when discharged, can be recharged by injecting direct current from an external source. In general, the operation of a battery is based on an electrochemical cell. Electrochemical cells have two electrodes. The anode and the cathode. The anode is defined as the electrode where oxidation takes place [gives up electrons] and the cathode where reduction takes place [picks up electrons].

Lithium-ion batteries are supposed to solve many of the problems present in the electric car industry, but like all electronic components they are prone to problems caused by the passage of energy. A feasible way to predict capacity degradation and possible mechanical failures in lithium-ion batteries is the analysis of macroparticles based on the Discrete Element Method [DEM] as this procedure performed correctly in the right software can save calculation time and give us a preview of the physical evidence of the problem we are facing.

Methodology

The Discrete Element Method [DEM] applied to the lithium-ion battery charging and discharging problem is more efficient than applying other types of numerical methods to solve it, as it fits perfectly with the type of problem being analysed in this project, unlike the Finite Element Method [FEM] where you can only do simulations in the elastic zone of a material, with DEM we can work in the elastic-plastic part and even in the plastic zone, that is to say with FEM we apply loads either physical, chemical or electrical and when removing them the material to analyse will recover in its totality its form and properties, this is of great utility when it is wanted to know a point of rupture, the quantity of load that supports a material, the pressure to which a pipe burst, etc. But what happens if we want to know at how many loads a material will break, if we apply a certain pressure on a pipe, at how many times it will have to be replaced to avoid damage. The need to use the Discrete Element Method arises from what has been investigated in this work as the different contributions in different areas of people or organisations that have applied this method to different problems related to the deformation of a material not only with the passage of time but also with the passage of the loads placed and removed in its useful life, as well as what is already known about lithium-ion batteries and their different characteristics:

Fernández-Gómez, Tomas, Fernández-Pérez, Vladimir Damian, Ramírez-Rodríguez, Ramón Rodolfo and Fernández-Pérez, Mitzy E. [2025]. Study of the discrete elements method in Lithium-ion batteries. Journal Electrical Engineering. 9[21]1-7: e2921107.
https://doi.org/10.35429/JEE.2025.9.21.2.1.7

Box 1

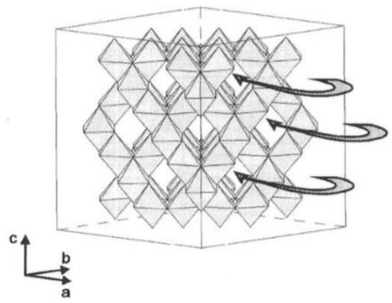


Figure 1

Empty channels defined in the three dimensions of space for the octahedral sublattice of spinel-like materials

Source: Micromechanical Models for Auxetic Materials

Discrete Element Method

The discrete element method is the decomposition of a physical model into smaller particles, which can be of different shapes such as circles, squares, triangles, etc., which are part of the analysis of the 2D method, or spheres, cylinders and tetrahedrons applying the 3D model. The purpose of this is to carry out a more detailed study of movement and fracture, by decomposing the element into smaller shapes we can analyse in particular how the body is affected at particle level according to the problem to be solved.

The figure below shows a solid drawn and discretised in the GiD software creating a total of 89,279 spheres and the same number of nodes.

Box 2

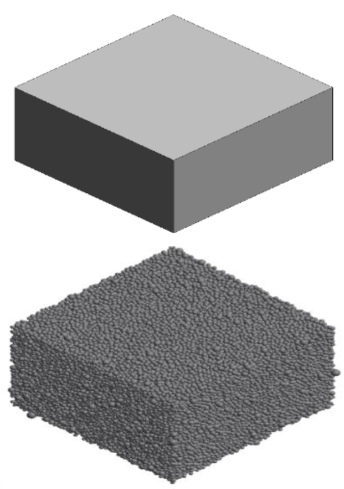


Figure 2

Representative cube in solid and discretised GiD

Source: HAIXU

1. Software

For the implementation of the method, the GiD software with its Kratos extension was used, this is a framework for multidisciplinary problem solving, within this branch of solution it was decided to work with the G-DEMPack complement as it has the necessary tools to establish the indispensable parameters both in the properties of the materials and in the solution strategy.

GiD is a pre and post processor for numerical simulation in science and engineering, designed to cover common needs in the field of numerical simulations from pre to post process such as:

- Geometric Modelling [CAD]
- Mesh generation.
- Definition of data analysis.
- Data transfer to analysis software.
- Post-processing operations.
- Visualisation of results.

Box 3

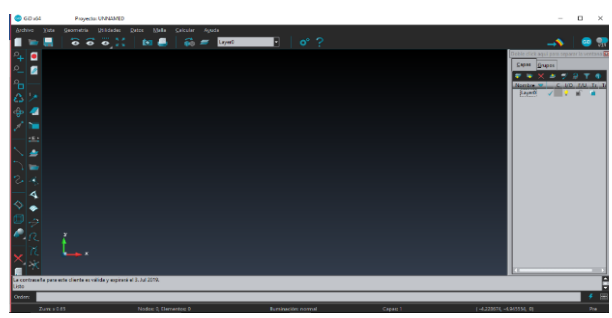


Figure 3

GiD user interface

Source :Own elaboration

Box 4

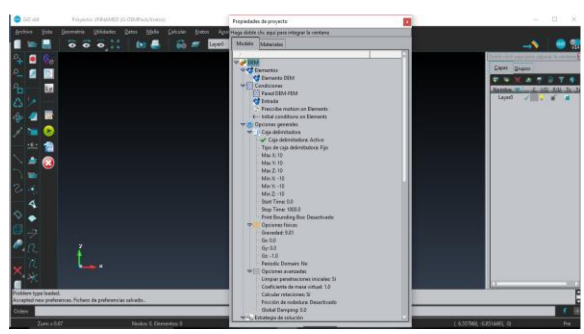


Figure 4

Window of the G-DEMPack Kratos extension

Source: Own elaboration

ISSN: 2523-2517
RENIECYT: 1702902

Fernández-Gómez, Tomas, Fernández-Pérez, Vladimir Damian, Ramírez-Rodríguez, Ramón Rodolfo and Fernández-Pérez, Mitzy E. [2025]. Study of the discrete elements method in Lithium-ion batteries. Journal Electrical Engineering. 9[21]1-7: e2921107.
https://doi.org/10.35429/JEE.2025.9.21.2.1.7

The use of this software was chosen because it requires less computing power compared to other programmes offered, as well as having a free licence for a period of one month, allowing us to use all the tools available in the paid version.

Graphical representation

Currently there are different types of electric battery arrangements, as already mentioned this depends on the needs of these, in this particular case we will talk about the batteries of electric vehicles.

Box 5

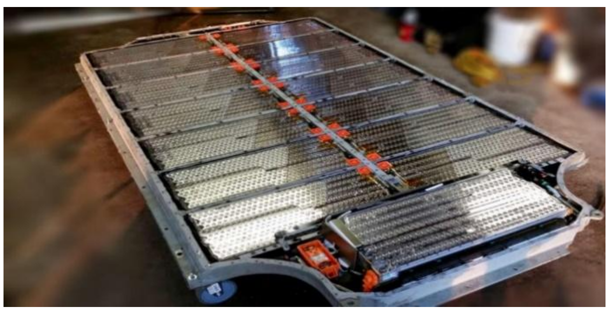


Figure 5
Tesla Model S Battery
Source: Hybrids and Electrics

Simulations

The standard dimensions of the layers composing the electrode were taken into account, ranging in the order of 100-300 µm as a whole and each individual layer between 20 and 35 µm. Three representative plates were drawn for each of the materials [graphite, polypropylene and lithium iron phosphate] with the above mentioned units. They were then decomposed into particles as shown in the following pictures

Box 6

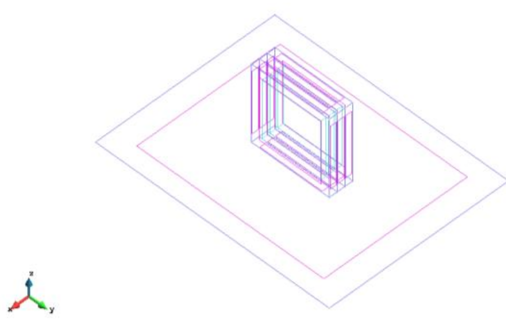


Figure 6
Drawing of the plates
Source: Own elaboration

Box 7

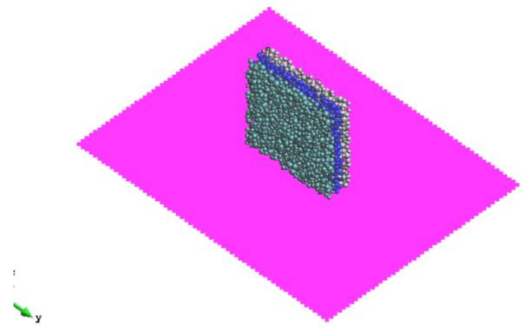


Figure 7
Discretised plates in spheres
Source: Own elaboration

The simulation below shows the passage of smaller particles representing the release of lithium ions [smaller blue particles] from the cathode [LiFePO_4] to the anode [graphite] through the separator [polypropylene].

Box 8

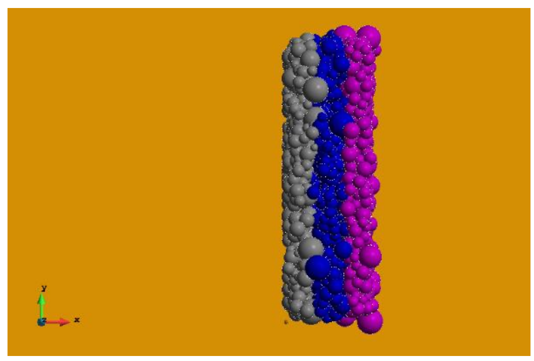


Figure 8
Starting position
Source: Own elaboration

Failure mechanism

Taking into account the simulation in figures 7 and 8, we can use the post-processing tool offered by the software for displacement analysis.

Box 9

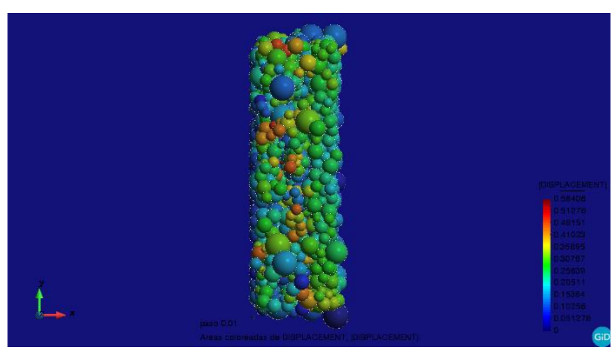


Figure 9
Post-processing starting position
Source: Own elaboration

ISSN: 2523-2517
RENIECYT: 1702902

Box 10

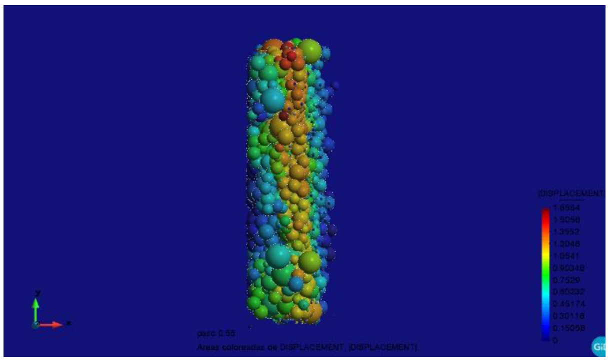


Figure 10
Position at the passage of half the time
Source: Own elaboration

Box 11

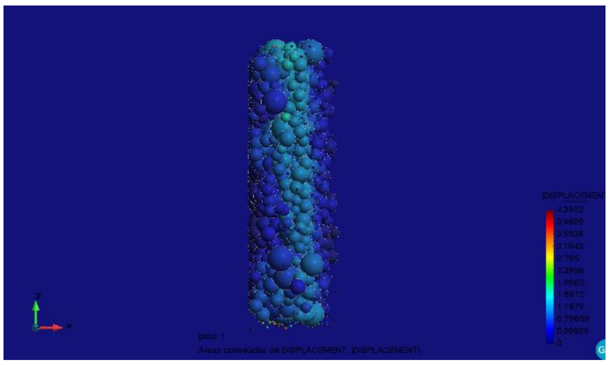


Figure 11
Final post-processing position
Source: Own elaboration

We can see in the previous images that the part with the greatest displacement is the intermediate plate, which corresponds to the separator material, in which red, yellow and green particles can be seen according to their degree of displacement, thus affirming that one of the main failures will be generated by wear in this part.

Local buckling

As we already know, local buckling will generate a very noticeable change in the structure with the appearance of bending points.

To appreciate this failure, one plate was taken into account, hiding the other two in a lateral view.

The figure of the final position represents this phenomenon, buckling at the bottom of it.

Box 12

Figure 12
Starting position
Source: Own elaboration

Box 13

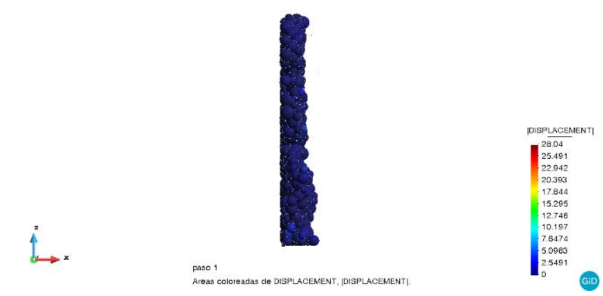


Figure 13
Final position
Source: Own elaboration

Conclusions

As seen so far, this project was primarily based on the collection of information about the problem to be solved. We found advances regarding the failures and lifespan of lithium-ion batteries. However, none of them included a graphical representation for understanding the problem, which was what was done in the presented work. The existence of these internal and microstructural phenomena, leading to mechanical failures such as the aforementioned: local buckling, vacuum onset, delamination, and loss of contact with the current collector, was verified.

Referring to the simulations section, the main cause of failures in these batteries is the change in the structure of the separator between the anode and cathode, generating direct contact between these two materials, which produces a short circuit, directly affecting their lifespan.

This project can be used as a basis for solving the problem of the lifespan of electric car batteries by optimizing the composition and manufacture of their electrodes.

ISSN: 2523-2517
RENIECYT: 1702902

The results obtained in other works along the same lines of research were also verified. We can conclude that the model created has reliable bases that can be implemented and improved to obtain more accurate results.

Authors' contribution

Fernandez-Gómez, Tomas: In charge of conducting the investigation

Fernandez-Perez, Vladimir Damian: In charge of literature search

Ramirez-Rodriguez, Ramón Rodolfo: In charge of defining the methodology to be used

Fernandez-Perez, Mitzy E: Data analysis and writing manager

Availability of data and materials

The articles used within the table and important points to support the information of this project are available.

The data used are those found through a literature search.

Funding

No financing of any kind was received.

Acknowledgments

Not applicable.

No institution, university or company participated in the financing of this research.

Abbreviations

CAD - Computer-Aided Design
DEM - Discrete Element Method
FEM - Finit Element Methot
MED - Método de Elementos Discretos

References

Basics

Baterías de Grafeno. [s.f.]. Obtenido de Baterías de Grafeno

Electrónica Unicrom. [s.f.]. Unicrom

hybridstein group. [s.f.]. Obtenido de hybridstein group

LOCTITE TEROSON. [s.f.]. Obtenido de LOCTITE TEROSON

Supports

Cabrera, S. [2012]. Perspectivas en el procesamiento de materiales - electrodos para baterías de ion litio en bolivia . revista boliviana de química , 24.

Cea, D. Á. [Julio de 2017]. Modelo para la batería de ion de litio de un vehiculo eléctrico. Valladolid, España.

D'Ambra, R. B. [2007]. Cálculo del factor de intensidad de tensiones utilizando el metodo de los elementos discretos . Revista Sul-Americana de Engenharia Estructural, 7-20.

D'Ambra, R. B. [2008]. Calculo de parametros fractomecanicos via integral j utilizando el metodo de los elementos discretos. Mecánica Computacional Vol XXVII, 1277-1291.

Durán, R. S. [08 de JULIO de 2013]. Diseño e implementación de un sistema de adquisición de datos para pruebas de carga y descarga de baterías de ion-litio. Santiago de Chile, Chile.

Fonseca, L. J. [01 de Enero de 2011]. Celdas, pilas y baterías de ionlitio una alternativa para….??? . pág. 8.

Garnica, A. G. [2015]. Patentamiento, trayectoria y características de las baterias automotrices: el caso de los autos híbridos. Entreciencias Diálogo en la sociedad del conocimiento, 17.

Garnica, A. G. [2015]. Patentamientro, trayectoria y características de las baterías automotrices Ell caso de los autos híbridos. Morelos: Universidad Autónoma del Estado de Morelos.

Instituto de Ciencia de Materiales de Madrid. [1995]. Batería de iones litio LÍ4/3TÍ5/3O41 LiCIO^ÍPC] I LiMn204. BOLETÍN DE LA SOCIEDAD ESPAÑOLA DE Cerámica y Vidrio, 8.

ISSN: 2523-2517
RENIECYT: 1702902

ITURBE, J. L. [Marzo de 2007]. Depósito y caracterización de películas delgadas de materiales con aplicación en cátodos para microbaterias recargables de litio. Toluca de Lerdo, Edo. de México, México.

Iznaga, Á. L. [2014]. Bases teóricas para la simulación del desgaste de los órganos de trabajo de los aperos de labranza mediante el Método de los Elementos Distintos [MED] . Revista Ciencias Técnicas Agropecuarias, 81-88.

Kosteski, L. [2008]. Determinación de parámetros factomecanicos estáticos y dinámicos utilizando el Método de Elementos Discretos compuestos por barras. Revista Internacional de Métodos Numéricos para Cálculo y Diseño en Ingenieria , 323-343.

Mendoza, G. A. [9 de abril de 2014]. Análisis de confiabilidad en un modelo de descarga de silos de almacenamiento mediante el Método de Elementos Discretos DEM. Bogotá, Colombia.

Navarra, E. O. [2005]. Analisis de mecánica de la fractura. avances en el desarrollo de los métodos de elementos discretos y de elementos finitos para el análisis de problemas de fractura. Barcelona, España.

Navarra, E. O. [Abril de 2005]. Aplicación del método de los elemento s discretos a problemas de desgaste. Barcelona, España.

Ordóñez, C. P. [Mayo de 2011]. Estudio de baterías para vehículos eléctricos. . Madrid, España.

Quispe, M. M. [6 de noviembre de 2013]. Formulación de elementos finitos y elementos discretos.

Reyes, C. E. [Noviembre de 2013]. Paralelización del Método de Elementos Discretos para el Análisis de Daño Después de una Explosión. Guanajuato, Gto. .

Velasco, A. C. [Julio de 2018]. Desarrollo y validación de un modelo de baterías ion-litio. aplicación del estudio de su envejecimiento ligado al tipo de recarga.

ISSN: 2523-2517
RENIECYT: 1702902

Journal Electrical Engineering 9[21]1-8: e3921108
Article

Kalman Filter: Optimal estimation in electrical, mechanical, and digital systems

Filtro de Kalman: Estimación óptima en sistemas eléctricos, mecánicos y digitales

Medécigo-Cabriales, Felipe A. [a], Alaffita-Hernández, Francisco Alejandro* [b], Colorado-Garrido, Dario [c] and Escobedo-Trujillo, Beatris Adriana [d]

[a] ROR Universidad Veracruzana • NHP-2388-2025 • 0009-0005-0619-3290 • 1318715
[b] ROR Universidad Veracruzana • CBW-0161-2022 • 0000-0002-7971-6356 • 216715
[c] ROR Universidad Veracruzana • H-1204-2018 • 0000-0003-4157-1005 • 171579
[d] ROR Universidad Veracruzana • AAC-2365-2022 • 0000-0002-8937-3019 • 173174

Classification:

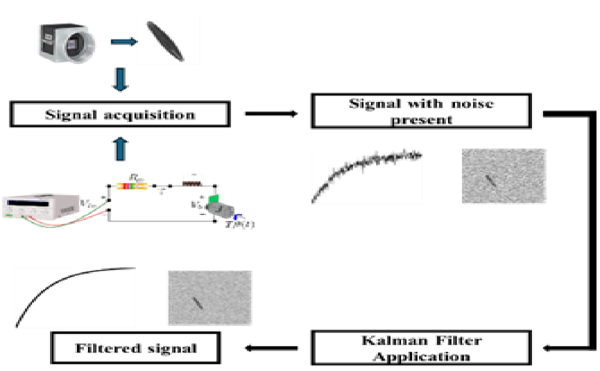
Area: Physics-Mathematics and Earth Sciences
Field: Mathematics
Discipline: Numerical analysis
Subdiscipline: Algorithm construction

https://doi.org/10.35429/JEE.2025.9.21.3.1.8
History of the article:
Received: March 30, 2025
Accepted: June 30, 2025

* ✉ [falaffita@uv.mx]

Abstract

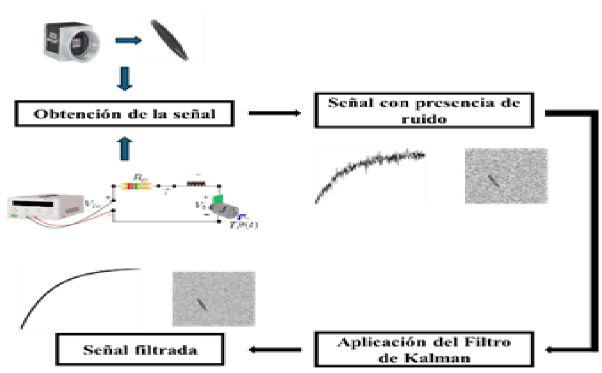
This work demonstrates the effectiveness of the Kalman filter for noise filtering in RLC circuits, speed estimation in direct current motors, and noise removal in digital images. The theoretical formulation of the filter is developed, along with its implementation in electrical and mechanical systems, and its extension through the reduced update Kalman filter [RUKF] for image processing. Experimental results validate that the filter provides accurate estimates under white Gaussian noise conditions, outperforming conventional methods in restoration and control tasks.



Kalman filter, RLC circuits, Image processing

Resumen

Este trabajo demuestra la efectividad del filtro de Kalman para el filtrado de ruido en circuitos RLC, la estimación de velocidad en motores de corriente directa y la eliminación de ruido en imágenes digitales. Se desarrolla la formulación teórica del filtro, su implementación en sistemas eléctricos y mecánicos, y su extensión mediante el filtro de Kalman de actualización reducida [RUKF] para el procesamiento de imágenes. Los resultados experimentales validan que el filtro proporciona estimaciones precisas bajo condiciones de ruido blanco gaussiano, superando métodos convencionales en tareas de restauración y control.



Filtro de Kalman, Circuitos RLC, Procesamiento de imágenes

Area: Promotion of frontier research and basic science in all fields of knowledge.

Citation: Medécigo-Cabriales, Felipe A., Alaffita-Hernández, Francisco Alejandro, Colorado-Garrido, Dario and Escobedo-Trujillo, Beatris Adriana. [2025]. Kalman Filter: Optimal estimation in electrical, mechanical, and digital systems. Journal Electrical Engineering. 9[21]1-8: e3921108.

Introduction

The Kalman filter is considered one of the most significant advances in estimation and control theory of the 20th century. It was developed by Rudolf Kalman in 1960 [Kalman, 1960]. This algorithm has demonstrated wide applicability across various engineering and applied science disciplines.

Its ability to estimate hidden states of dynamic systems from noisy measurements makes it an essential tool in aerospace navigation, robotics, biomedical signal processing and digital image analysis [Grewal & Andrews, 2001]. Its relevance lies in its computational efficiency and robust mathematical foundation, which make it suitable for real-time applications with limited computational resources.

From a theoretical perspective, this filter is distinguished by its statistical optimality under specific conditions. When the system can be modelled as linear and the involved noises are Gaussian and white, the filter provides estimates that minimise the mean squared error [Maybeck, 1979]. This property differentiates it from other filtering techniques such as Wiener filters, which require a priori knowledge of signal statistics, or wavelet transform-based methods that, while effective for certain noise types, lack the predictor-corrector framework characteristic of the Kalman approach [Simon, 2006]. Furthermore, its recursive nature enables efficient implementations that update estimates as new data arrive, providing an advantage for real-time control systems.

The Kalman filter's characteristics confer far-reaching practical implications. In electrical engineering, for instance, thermal noise in RLC circuit measurements distorts voltage and current signals, compromising the accuracy of associated control systems [Escobedo-Trujillo & Garrido, 2018].

Similarly, in electromechanical systems such as DC motors, disturbances in angular velocity measurements may undermine the performance of advanced control strategies [Reymundo et al., 2018]. The Kalman filter addresses these challenges by optimally combining physical model predictions with available experimental observations.

In the domain of image processing, two-dimensional variants of the Kalman filter, such as the Reduced-Update Kalman Filter [RUKF], have proven particularly effective for restoration and noise removal tasks [Fronckova & Slaby, 2020]. Unlike traditional convolution-based approaches or frequency-domain methods, the RUKF accounts for the spatial correlation structure between pixels, enabling superior preservation of edges and fine details during filtering. This capability has established it as a valuable alternative for applications ranging from medical image processing to satellite photo enhancement, where visual quality and information fidelity are critical.

This work demonstrates the effectiveness of the Kalman filter in three key applications: noise filtering in RLC circuits, speed estimation in D.C. motors, and noise removal in images. The central hypothesis states that the filter provides optimal solutions when the system can be adequately modelled and the noise is characterisable.

The presented work will be structured as follows:

1. Theoretical foundations of the Kalman Filter
2. Implementation in RLC electrical circuits
3. Application to D.C. motor control
4. Image processing with RUKF
5. Conclusions

Methodology

The Kalman filter is an optimal recursive estimator for linear dynamic systems affected by Gaussian noise. Its mathematical structure derives from the first-order linear equations that describe the system.

The system dynamics are given by

$$\dot{x}(t) = Ax(t) + w[t] \qquad [1]$$

while the observations are given by

$$z(t) = Hx(t) + v(t) \qquad [2]$$

where $x(t)$ is the system state, A is the coefficient matrix of the dynamic system, b is the input coupling, $w(t), v(t)$ are the noise for the state and observations respectively, $H(t)$ is the system observation matrix, and z[t] are the observations. The set of equations [1] and [2] is called *the process plant*.

ISSN: 2523-2517
RENIECYT: 1702902

Medécigo-Cabriales, Felipe A., Alaffita-Hernández, Francisco Alejandro, Colorado-Garrido, Dario and Escobedo-Trujillo, Beatris Adriana. [2025]. Kalman Filter: Optimal estimation in electrical, mechanical, and digital systems. Journal Electrical Engineering. 9[21]1-8: e3921108.
https://doi.org/10.35429/JEE.2025.9.21.3.1.8

The first step to apply the filter equations is to assign initial values to the dynamic system: $x(t_0)$, the covariance of the estimated state $P_0(t)$ and the measurement covariance matrix R. This allows calculation of the Kalman gain through:

$$K_n(t) = P_{n-1}(t)H^T(HP_{n-1}(t)H^T + R)^{-1} \quad [3]$$

Once the Kalman gain is obtained, the estimated state can be updated:

$$\hat{x}_n(t) = \hat{x}_{n-1}(t) + K_n(t)\left(z_n(t) - H\hat{x}_{(n-1)}(t)\right)[4]$$

Similarly, the estimation covariance can be updated:

$$P_n(t) = [I - K_n(t)H]P_n(t) \quad [5]$$

On the other hand, a state estimate is required. For this purpose, the analytical solution of the deterministic part of the dynamic system [1] is used:

$$\hat{x}_{n+1}(t) = \phi(t)\hat{x}_n(t) \quad [6]$$

To complete the formulation, where $\phi(t) = e^{tA}$, the covariance for the estimated state $\hat{x}(t)$ is computed as:

$$P_{n+1}(t) = \phi(t)P_n(t)\phi(t)^T + Q(t) \quad [7]$$

The process noise covariance matrix $Q(t)$ characterizes the model uncertainty:

$$Q(t) = \phi(t)\left[\int_0^T \phi(t)^{-1}w(t)(\phi(t)^T)^{-1}\,dt\right]\phi(t)^T \quad [8]$$

with $w(t) = \begin{bmatrix} 0 & 0 \\ 0 & q \end{bmatrix}$ representing the process covariance matrix for $x(t)$ in equation [8].

This procedure is iterative and repeats until $N - 1$, where N represents the number of measured data points.

The Kalman filter was originally designed for one-dimensional time-varying dynamic systems, where signals vary along a single dimension [time]. However, its application to image processing requires extension to two dimensions [space]. In this regard, various authors have proposed modifications to the filter for digital image noise reduction.

Woods and Radewan [1977] introduced a modified version of the Kalman filter for this purpose, called the Reduced-Update Kalman Filter [RUKF]. The model is based on the state equation of the two-dimensional autoregressive [2D AR] model [Woods, 2011] given by:

$$x(i,j) = \sum_{(k,l)\in\mathcal{D}} \phi(k,l)x(i-k,j-l) + w[i,j] \quad [9]$$

where $x(i,j)$ is the pixel value at position (i,j) of the ideal image, $\phi(k,l)$ are the autoregressive model parameters, $w(i,j)$ is the system noise [process noise], typically assumed to be zero-mean Gaussian noise with covariance matrix Q.

The image degraded by additive noise is modelled as

$$z(i,j) = x(i,j) + v(i,j) \quad [10]$$

where $z(i,j)$ is the observed pixel value [degraded image] and $v(i,j)$ is the measurement noise [also Gaussian, with covariance matrix R].

If the image is degraded by blur, the measurement equation is extended to

$$z(i,j) = \sum_{[k,l]} h(k,l)x(i-k,j-l) + v(i,j) \quad [11]$$

where $h(k,l)$ is the blur kernel.

RUFK Algorithm.

The RUFK algorithm converts the two-dimensional problem into a one-dimensional problem through sequential scanning of the image [pixel by pixel starting from the upper left corner, proceeding row by row until completion]. At each step, the Kalman filter is only applied to a local region around the current pixel, reducing computational load [Woods & Ingle, 1981].

The algorithm steps are shown below.

1. Prediction

$$\hat{x}_{k[-]} = \Phi_{k-1}\hat{x}_{k-1(+)} \quad [12]$$

$$P_{k(-)} = \Phi_{k-1}P_{k-1(+)}\Phi_{k-1}^{\mathrm{T}} + Q_{k-1} \quad [13]$$

2. Correction

$$\hat{x}_{k[+]} = \hat{x}_{k[-]} + K_k\left[z_k - H_k\hat{x}_{k(-)}\right] \quad [14]$$

ISSN: 2523-2517
RENIECYT: 1702902

Medécigo-Cabriales, Felipe A., Alaffita-Hernández, Francisco Alejandro, Colorado-Garrido, Dario and Escobedo-Trujillo, Beatris Adriana. [2025]. Kalman Filter: Optimal estimation in electrical, mechanical, and digital systems. Journal Electrical Engineering. 9[21]1-8: e3921108.
https://doi.org/10.35429/JEE.2025.9.21.3.1.8

$$P_{k(+)} = P_{k(-)} - K_k H_k P_{k(-)} \quad [15]$$

$$K_k = P_{k(-)} H_k^T \left[H_k P_{k(-)} H_k^T + R_k\right]^{-1} \quad [16]$$

where $\hat{x}_{k(-)}$ and $\hat{x}_{k(+)}$ are the a priori and a posteriori state estimates [i.e., the pixel value], $P_{k(-)}$ and $P_{k(+)}$ are the error covariance matrices and K_k is the Kalman gain.

To implement the RUKF, the order and parameters of the 2D AR model must be determined using the maximum entropy principle [Bouzouba & Radouane, 2000].

The first step involves computing the estimation error for different model orders $\theta(p,q)$

$$\hat{e}_\theta = z - \tilde{x}_\theta \quad [17]$$

Subsequently, the θ order that maximizes entropy is selected:

$$H(\hat{g}_\theta) = -\sum_{i,j} \hat{g}_\theta(i,j) \log\left(\hat{g}_\theta(i,j)\right) \quad [18]$$

where $\hat{g}_\theta[i,j]$ represents the estimated probability density of the error.

Applications

Below are the three applications to be addressed in this work.

Series RLC Circuit.

Figure 1 shows the series-connected RLC circuit.

Box 1

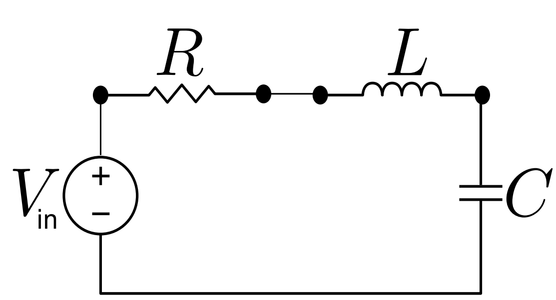


Figure 1
RLC circuit

Source: Own elaboration.

From Ohm's and Kirchhoff's laws [Sadiku, 2006], the dynamic behaviour of the charge $q(t)$ in an RLC circuit is given by:

$$\frac{d^2q(t)}{dt^2} = -\frac{1}{LC}q(t) - \frac{R}{L}\frac{dq(t)}{dt} + \frac{V}{L} \quad [19]$$

where $q(t)$ is the electric charge, R is the resistor value, L is the inductance value, C is the capacitance value and V is the circuit input voltage.

To apply the Kalman filter equations, the dynamic system must be expressed in matrix form:

$$\dot{Q}(t) = AQ(t) + b \quad [20]$$

With

$$Q(t) = \begin{bmatrix} q[t] \\ q'[t] \end{bmatrix}, A = \begin{bmatrix} 0 & 1 \\ -\frac{1}{LC} & -\frac{R}{L} \end{bmatrix} \text{ y } b = \begin{bmatrix} 0 \\ \frac{V}{L} \end{bmatrix}$$

Where $Q_0 = \begin{bmatrix} q[0] \\ q'[0] \end{bmatrix}$ represents the system's initial condition.

Given the presence of disturbances [noise], the deterministic differential equation shown in [20] cannot fully model the process. Therefore, an additional equation is required to model this perturbation. Assuming additive white noise, we obtain:

$$\frac{dQ[t]}{dt} = AQ(t) + b + w(t) \quad [21]$$

Experimental Process. To analyse the behaviour of the RLC circuit, the circuit was built on a DIGIAC D3000 1.2 module with the following component values:

- R = 10 $k\Omega$
- L = 36 H
- C = 100 nF

Voltage measurements across the capacitor and data storage were performed using:

- A National Instruments [NI] 9220 card [connected to the circuit output]
- An NI 9263 module [connected to the circuit input] [see Tables 1 and 2].

Data acquisition was carried out using LabVIEW software. White noise with a variance of 1 was added to the measured voltage. All data were plotted in MATLAB to observe the circuit voltage behaviour.

ISSN: 2523-2517
RENIECYT: 1702902

Box 2

Table 1

NI-9220 Module Specifications.

NI-9220 Voltage Input Module [C Series]	
Number of Channels	**16 analogue input channels**
ADC Resolution	**16-bit**
ADC Type	**Successive Approximation Register [SAR]**
Input Voltage Ranges	
Measurement Voltage	
Minimum	$\pm 10.4V$
Typical	$\pm 10.5V$
Maximum	$\pm 10.5V$
Overvoltage Protection	**±30V**
Conversion Time	**30µs minimum**
Sampling Rate	**100kS/s maximum**

Source: Own elaboration

Box 3

Table 2

NI-9263 Module Specifications

NI-9263 Voltage Output Module [C Series]	
Channel Count	**4 analogue output channels**
DAC Resolution	**16-bit**
DAC Type	**String**
Power-On State	**Channels disabled**
Start-Up Voltage	$0V$
Power-Down Voltage	$0V$
Voltage Ranges	
Nominal	$\pm 10V$
Minimum	$10.4V$
Typical	$\pm 10.7V$
Maximum	$\pm 11V$
Overvoltage Protection	**±30V**
Current Capacity	**±1mA per channel [max]**
Output Impedance	**2Ω**

Source: Own elaboration

Application of the Kalman Filter to the Series RLC Circuit. Given the differential equation of the RLC circuit [21], and assuming the observations are $z(t) = H(t)x(t) + v(t)$, $H = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$

$$z(t) = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} q[t] \\ q'[t] \end{bmatrix} + v[t] \qquad [22]$$

with initial conditions $x(0) = [0;0]$, $P(0) = [2,0;0,2]$, $\hat{Q}d(0) = \begin{bmatrix} 0 & 0 \\ 0 & q \end{bmatrix}$.

For the development of the Kalman filter algorithm in MATLAB, it is necessary to know Φ, $\hat{Q}$ and Ψ. Given that $\Phi(t) = e^{tA}$, where A is the dynamic coefficient matrix of the model in [21], it follows that

$$\Phi(t) = \begin{bmatrix} e^{-\alpha t}\left(\cos(\beta t) + \frac{R\sin[\beta t]}{\sqrt{\frac{4L}{C} - R^2}}\right) & \frac{2e^{-\alpha t}L\sin[\beta t]}{\sqrt{\frac{4L}{C} - R^2}} \\ -\frac{2e^{-\alpha t}\sin[\beta t]}{C\sqrt{\frac{4L}{C} - R^2}} & e^{-\alpha t}\left(\cos(\beta t) - \frac{R\sin[\beta t]}{\sqrt{\frac{4L}{C} - R^2}}\right) \end{bmatrix} \qquad [23]$$

similarly, $\delta(t) = \Phi[t]\int_0^T \Phi(t)^{-1} bdt$, thus

$$\delta(t) = \begin{pmatrix} V[-e^{-\alpha t}\cos(\beta t) - \frac{e^{-\alpha t}R\sin[\beta t]}{\sqrt{\frac{4L}{C} - R^2}} \\ \frac{2e^{-\alpha t}V\sin(\beta t)}{\sqrt{\frac{4L}{C} - R^2}} \end{pmatrix} \qquad [24]$$

finally, $\hat{Q}d = \Phi(t)\Psi(t)\Phi(t)^T$, where $\Psi(t) = \int_0^T \Phi(t)^{-1}\,\hat{Q}_1(\Phi(t)^T)^{-1}$ [25]

This allows for the proper implementation of the filter.

The application of the filter to the circuit, composed of a 10 $k\Omega$ resistor, a 36 H inductor, and a 100 nF capacitor connected in series to a 5 V power supply, can be observed in Figure 2.

Box 4

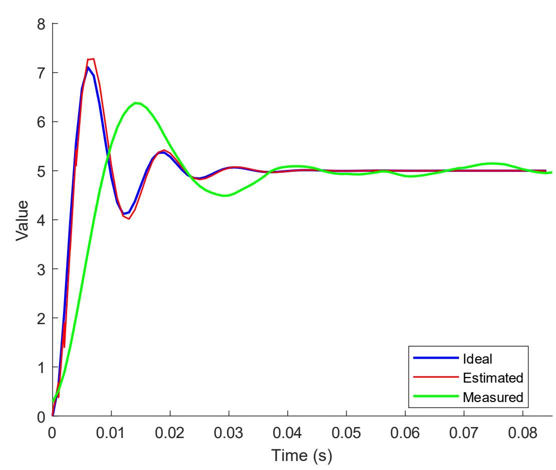


Figure 2

Comparison of Measured Data, the Deterministic [Ideal] Model, and the Estimated Model [Filtered Signal].

Source: Own elaboration.

Angular Velocity in a Direct Current Motor.

A direct current [DC] motor is an electrical rotating machine that converts electrical energy into mechanical energy [Harper, 1999].

ISSN: 2523-2517
RENIECYT: 1702902

Medécigo-Cabriales, Felipe A., Alaffita-Hernández, Francisco Alejandro, Colorado-Garrido, Dario and Escobedo-Trujillo, Beatris Adriana. [2025]. Kalman Filter: Optimal estimation in electrical, mechanical, and digital systems. Journal Electrical Engineering. 9[21]1-8: e3921108.
https://doi.org/10.35429/JEE.2025.9.21.3.1.8

Figure 3 illustrates the equivalent circuit diagram of a DC motor, which includes a variable power supply providing an input voltage of $V_{in} = 24V$. The equivalent circuit comprises a resistance of $R_m = 5.2\Omega$, an inductance of $L = 1.1mH$ and a moment of inertia of $J = 0.01\ kg \cdot m$ on the shaft. The values of torque T, the angular position of the shaft $\theta(t)$, $K_T = 0.75\ N \cdot m \cdot A^{-1}$ and $K_b = 0.75\ N \cdot mA^{-1}$ were obtained from the published work of Emhemed & Mamat [2012].

Box 5

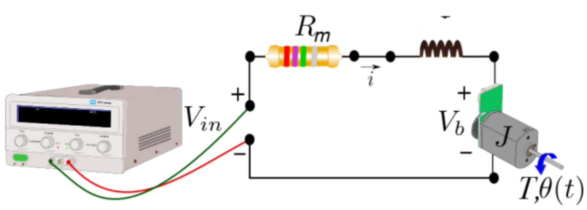


Figure 3

Direct Current Motor Circuit

Source: Own elaboration.

The differential equation associated with this system was presented in the work by Escobedo-Trujillo & Garrido [2018], yielding:

$$\frac{d\Theta[t]}{dt} = A\Theta(t) + b \qquad [26]$$

With

$$A = \begin{pmatrix} 0 & 1 \\ 0 & -\frac{K_T K_b}{R_m J} \end{pmatrix}, b = \begin{pmatrix} 0 \\ \frac{K_T V_{in}}{R_m J} \end{pmatrix}, \Theta(t) = \begin{pmatrix} \theta \\ \frac{d\theta}{dt} \end{pmatrix}.$$

Once the dynamic system [26] is established, the Kalman filter equations can be applied with initial conditions. Figure 4 presents the results of applying the filter to the measured motor velocity.

Box 6

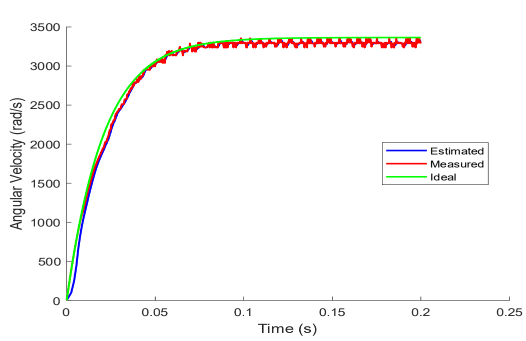


Figure 4

Comparison of Measured Data, Deterministic [Ideal] Model and Estimated Model [Filtered Signal]

Noise removal in digital images using Kalman filtering.

The Reduced Update Kalman Filter [RUKF] was implemented to improve the quality of seed images that had been injected with Gaussian noise.

The filter proved effective for:

1. Preserving fine structures. The RUKF successfully maintained edges and details in the seed images, essential for subsequent morphological analyses.
2. Noise reduction. In conducted tests, the filter improved the peak signal-to-noise ratio [PSNR], showing performance comparable to other filtering methods [see Table 3].

The algorithm follows this workflow:

1. Processing. Images are resized to 512 × 512 pixels and converted to grayscale to standardise the process.
2. Spatial modelling. An autoregressive model is used that considers the correlation between each pixel and its immediate neighbours.
3. Adaptive filter. It dynamically adjusts its parameters according to the image's local characteristics.

Figure 5 shows the original image, a photograph of an *Aegilops cylindrica* seed, to which Gaussian noise was subsequently injected.

Box 7

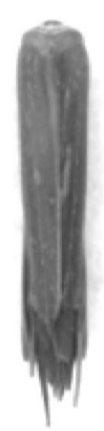


Figure 5

Photograph of an Aegilops cylindrica seed

Source: Original capture using a Basler acA3088-57um camera.

ISSN: 2523-2517
RENIECYT: 1702902

Gaussian noise with an intensity of $\sigma = 0.3$ was injected. To provide a comparison benchmark, in addition to the Kalman filter, a Gaussian filter and a median filter were applied to the image, as can be seen in Figure 6.

Box 8

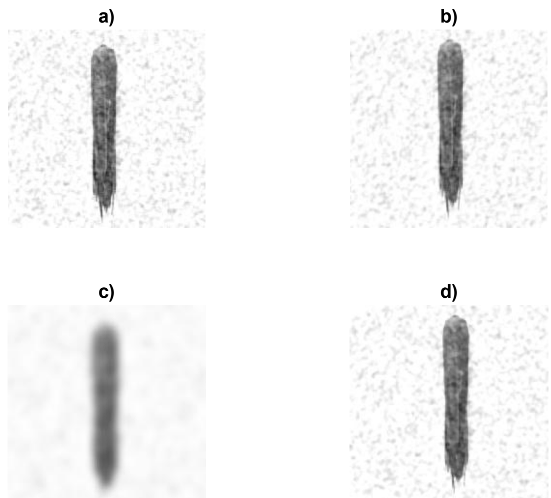


Figure 6

Comparison between a] noisy image, b] Kalman-filtered image, c] Gaussian-filtered image, and d] median-filtered image.

Source: Own elaboration.

PSNR is a metric used to quantitatively evaluate the quality of processed images [Fonckova & Slaby, 2020]. It measures how much an image has degraded due to noise or compression/filtering processes by comparing it with an original reference image.

The Kalman filter achieved $PSNR = 27.7443\,dB$, while the Gaussian and median filters obtained values of $29.6278\,dB$ and $28.2565\,dB$ respectively. Although the Kalman filter is not typically used as frequently in image cleaning as other filters [Gonzales & Wintz, 1987], it produces competitive results when compared with more conventional filters, offering one particular advantage: it is especially useful when maximum preservation of details regarding edges and textures is required [Woods, 2011].

Conclusions

The Kalman filter proved to be an effective tool for filtering noise-contaminated signals in electrical, mechanical, and image processing applications. In RLC circuits and DC motors, it enabled accurate system state estimations, improving acquired data quality.

For image processing, its RUKF implementation preserved important details while significantly reducing noise. The results confirm that, with proper modelling and under white Gaussian noise conditions, the filter outperforms traditional methods. Future work may explore its adaptation to non-linear systems and non-Gaussian noise environments.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Medécigo-Cabriales, Felipe A.: Was responsible for results interpretation, figure preparation, and drafting the initial manuscript.

Alaffita-Hernández, Francisco A.: Implemented the algorithm programming, study conceptualisation, contributed to methodological development, and participated in results validation.

Colorado-Garrido, Dario: Contributed to manuscript editing, technical content review, and methodological coherence.

Escobedo-Trujillo, Beatris A.: Participated in style correction, grammatical review, and final text adaptation to editorial guidelines.

Availability of data and materials

Given the nature of this work, the collected data were made available.

Funding

The research was not funded.

Abbreviations

AR	Autoregressive
DC	Direct Current
EKF	Extended Kalman Filter
NI	National Instruments
PSNR	Peak Signal-to-Noise Ratio
RLC	Resistor, Inductor, Capacitor
RUKF	Reduced Update Kalman Filter

SAR	Successive Approximation Register
UKF	Unscented Kalman Filter

References

Antecedents

Escobedo-Trujillo, B., & Garrido, J. [2018]. Modeling of systems using Itô's stochastic differential equations. *Revista Mexicana de Ingeniería Química, 17*[2], 1–12.

Kalman, R. E. [1960]. A new approach to linear filtering and prediction problems. *Journal of Basic Engineering, 82*[1], 35–45.

Woods, J. W., & Radewan, C. H. [1977]. Kalman filtering in two dimensions. *IEEE Transactions on Information Theory, 23*[4], 473–482.

Basics

Bouzouba, K., & Radouane, L. [2000]. Image identification and estimation using the maximum entropy principle. *Pattern Recognition Letters, 21*[8], 691–700.

Chui, C. K., & Chen, G. [2009]. *Kalman Filtering with Real-Time Applications* [4th ed.]. Springer.

Grewal, M. S., & Andrews, A. P. [2001]. *Kalman Filtering: Theory and Practice with MATLAB*. Wiley.

Maybeck, P. S. [1979]. *Stochastic Models, Estimation, and Control, Volume 1*. Academic Press.

Sadiku, M. A. [2006]. *Fundamentos de circuitos eléctricos*. McGraw Hill.

Simon, D. [2006]. *Optimal State Estimation: Kalman, H∞, and Nonlinear Approaches*. Wiley.

Woods, J. W. [2011]. *Multidimensional signal, image, and video processing and coding* [2nd ed.]. Academic Press.

Gonzales, R. C., & Wintz, P. [1987]. *Digital image processing*. Addison-Wesley Longman Publishing Co., Inc.

Harper, G. E. [1999]. *Control de motores eléctricos*. Editorial Limusa.

Supports

Citrin, S., & Azimi-Sadjadi, M. R. [1992]. A full-plane block Kalman filter for image restoration. *IEEE Transactions on Image Processing, 1*[4], 488–495.

Fronckova, K., & Slaby, A. [2020]. Kalman filter employment in image processing. In *Computational Science and Its Applications–ICCSA 2020: 20th International Conference, Cagliari, Italy, July 1–4, 2020, Proceedings, Part I 20* [pp. 833–844]. Springer International Publishing.

Reymundo, R. B., Alberto, V. M. F., Fermín, M. S., Eduardo, C. H. C., Amador, M. G. O., & Armando, O. L. J. [2018]. Control de velocidad de un motor de CD basado en mediciones de la corriente de armadura Speed control of a DC motor based on armature current measurement. *Ingeniería Investigación y Tecnología, 19*[4], 1–10.

Woods, J. W., & Ingle, V. K. [1981]. Kalman filtering in two dimensions: further results. *IEEE Transactions on Acoustics, Speech, and Signal Processing, 29*[2], 188–197.

Emhemed, A. A., & Mamat, R. B. [2012]. Modelling and simulation for industrial DC motor using intelligent control. *Procedia Engineering, 41*, 420–425.

ISSN: 2523-2517
RENIECYT: 1702902

Medécigo-Cabriales, Felipe A., Alaffita-Hernández, Francisco Alejandro, Colorado-Garrido, Dario and Escobedo-Trujillo, Beatris Adriana. [2025]. Kalman Filter: Optimal estimation in electrical, mechanical, and digital systems. Journal Electrical Engineering. 9[21]1-8: e3921108.
https://doi.org/10.35429/JEE.2025.9.21.3.1.8

Journal Electrical Engineering 9[21]1-5: e4921105

Article

Implementation of single-line diagrams for an electrical substation Ref

Implementación de diagramas unifilares para una subestación eléctrica tipo Ref

Rosas-Ortiz, Lenin Jacobo * [a], Molina-García, Moises [b], Fuentes-Ramos, Francisco [c] and Díaz-Cogco, Jonathan [d]

[a] ROR Tecnológico Nacional de México - Instituto Tecnológico Superior de Huatusco • AAU-10462-2021• 0000-0003-4974-5866 • 3447729

[b] ROR Tecnológico Nacional de México - Instituto Tecnológico Superior de Huatusco • KCZ-3165-2024• 0000-0002-4213-9591 • 311075

[c] ROR Tecnológico Nacional de México - Instituto Tecnológico Superior de Huatusco • KYR-9317-2024 • 0000-0002-7490-784X • 732279

[d] ROR Tecnológico Nacional de México - Instituto Tecnológico de Superior de Huatusco • 0000-0002-5201-5517 • 1267487

Classification:

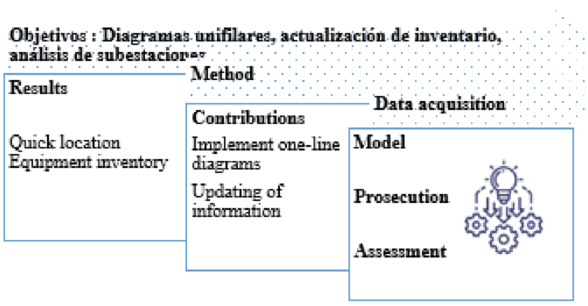
Area: Engineering
Field: Engineering
Discipline: System engineer
Subdiscipline: Electrical and electronic industry

https://doi.org/10.35429/JEE.2025.9.21.4.1.5
History of the article:
Received: March 19, 2025
Accepted: May 30, 2025

* ✉ [lrosaso@huatusco.tecnm.mx]

Abstract

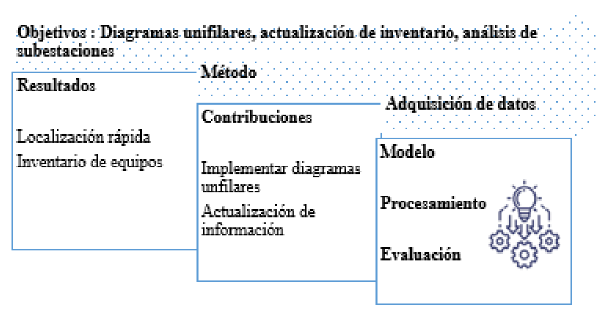
During the last years modifications or changes have been made in the facilities of the company under study, without taking into account the identification of switches and the modifications in the single-line diagrams, resulting in an outdated data and confusion in the location of circuits, as well as their values. The present study analyzed each of the existing electrical substations, data was collected and the single-line diagrams were updated to have more accurate information in case of an emergency or failure in the system. The electrical system associated with the facilities of the company under study, it has 9 electrical substations, [Main Substation, WM1, WM2, EPS, INJ1, INJ2, REF1, REF2 and REF3], the main substation receives the energy supplied by the CFE electrical substation with 115 KVA power.



Subestación eléctrica, mantenimiento, diagrama unifilar

Resumen

Durante los últimos años se han realizado modificaciones o cambios en las instalaciones de la empresa en estudio, sin tener presente la identificación de interruptores y las modificaciones en los diagramas unifilares, trayendo como consecuencia una desactualización de datos y confusión en la ubicación de circuitos, así como sus valores. El presente estudio analizó cada una de las subestaciones eléctricas existentes, se realizó el levantamiento de datos y se actualizaron los diagramas unifilares para tener una información más precisa en caso de presentarse alguna emergencia o falla en el sistema. El sistema eléctrico asociado a las instalaciones de la empresa en estudio, posee 9 subestaciones eléctricas, [Subestación Principal, WM1, WM2, EPS, INJ1, INJ2, REF1, REF2 y REF3], la subestación principal recibe la energía suministrada por la subestación eléctrica CFE con alimentación 115 KVA.



Electrical substation, maintenance, single-line diagram

Area: Development of strategic leading-edge technologies and open innovation for social transformation

Citation: Rosas-Ortiz, Lenin Jacobo, Molina-García, Moises, Fuentes-Ramos, Francisco and Díaz-Cogco, Jonathan. [2025]. Implementation of single-line diagrams for an electrical substation Ref. Journal Electrical Engineering. 9[21]1-5: e4921105.

Introduction

The study focused on the plant's electrical substations, using measuring instruments to gather more accurate and realistic information. The plans provided by the company were followed up on for updating and facilitating future modifications, whether for maintenance or expansion.

This compilation of substation plans and technical data provides greater insight into the plant's electrical system, facilitating maintenance planning.

This project was developed with the support of the plant's electrical substation personnel. We were provided with existing plans, protective equipment [PPE], and the necessary measuring equipment.

Development

The electrical system of the company under study consists of eight medium-voltage substations [34,500–440/380 V], not including the main high-voltage substation [115 kV], which is supplied by the Vista Norte substation. The transformers are the links between the power system's generators and the transmission lines, and between lines of different voltages. [Plata E. A., 2010]. This power supply comes through an underground connection with a 750 kcmil-xlp phase conductor, which reaches the lightning arresters. Lightning arresters are protective devices that limit the voltage on the equipment by discharging or diverting the overvoltage current.

Box 1

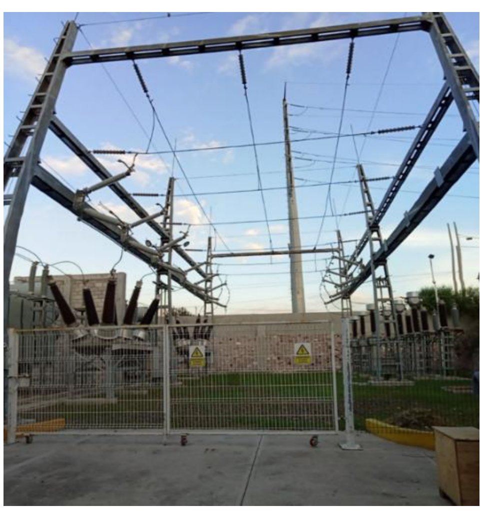


Figure 1
Main high voltage substation [115 KV]

This voltage passes through measuring devices called current transformers [CTs]. They are designed to reduce the intensity to manageable values proportional to the primary current in the secondary transformers, separating measuring instruments, meters, relays, etc. from the high-voltage circuit.

Precisely modeling and measuring the grounding system in a substation is vitally important to ensure system operation. [David Rieske, 2012]

After passing through the measuring systems, the voltage passes through the high-voltage switches, which can be mechanically opened in the event of an electrical fault due to overcurrent or any other factor that could affect the transformer.

Finally, the voltage reaches the transformer's primary with a transformation ratio of 115 to 34.5 KVA, maintaining power. The secondary output of TR1 is distributed with a 750 KCMIL conductor.

In the event of a TR1 failure, the backup TR2 is interconnected within the same high-voltage bus, so that it remains online when the switches are activated.

The medium-voltage lines exiting TR1 are routed through underground conduits to the main medium-voltage bus, consisting of SF6 gas switches. There is a three-pole busbar where 11 switchgear cells are independently branched off.

Verification of regulatory framework for the construction of reference-type substations.

- Verification of acquisitions, leases, service contracts, and execution of works by the Federal Electricity Commission.
- Application of the Law and regulations in the Federal Electricity Commission.
- Specification CFE DCCSSUBT
- Specification CFE DCCIAMBT• Procedure for Addressing Requests for Electric Power Service [PROASOL].
- Operating Regulations of the Distribution Electric System.
- Safety and Hygiene Regulations for fieldwork. [ELECTRICIDAD, 2022]

ISSN: 2523-2517
RENIECYT: 1702902

Rosas-Ortiz, Lenin Jacobo, Molina-García, Moises, Fuentes-Ramos, Francisco and Díaz-Cogco, Jonathan. [2025]. Implementation of single-line diagrams for an electrical substation Ref. Journal Electrical Engineering. 9[21]1-5: e4921105.
https://doi.org/10.35429/JEE.2025.9.21.4.1.5

Journal Electrical Engineering 9[21]1-5: e4921105
Article

Methodology

The main substation's protections include overcurrent protection relays, directional overcurrent protection, differential protection, distance protection, and power transformer protection.

Additionally, the transformer itself has its own protections, such as thermal protection, pressure protection, and oil level protection. All of these protections quickly isolate the fault when any anomaly or variation in values that could damage the equipment is detected. [Harper, 2010]

Both transformers have their own protection panels. These lines are also routed from the main substation through underground conduits at approximately 53 m to overhead transmission lines, which are made up of four 4/0 AWG ACSR transmission lines, approximately 900 m long. Each line supplies a specific area.

Box 2

Figure 2
TR1 control cabinet

The transmission lines are lowered to the "WM1" substation through underground conduits, where they reach the main service connection. If the backup transmission line is required, a secondary service connection is connected to the line.

It then passes through a vacuum interrupter, which acts as general protection for the substation. A busbar with three disconnectors connected in parallel is then connected.

Disconnector #1 has a 50 A fuse and is out due to a system failure. Therefore, a temporary link between the electromagnetic switches was established while the failure is corrected.

Disconnector #2, the switching equipment for transformer 2, has a 50 A fuse. The output of the disconnector, with a 1/0 AWG-XLP conductor, is distributed to the 2000 KVA TR2, with a transformation ratio of 34.5 KVA at 380 V. The transformer secondary output is distributed via 8 wires per phase with a 500 KCMIL conductor, which feeds the Siemens TDG1 electromagnetic switch with a 3200 A capacity, responsible for protecting the breakers within panels A and B.

The link is a derivation of the TDG1 that feeds the electromagnetic of the TDG2 brand SIEMENS with a capacity of 1200 A, this is responsible for protecting the switches inside panels C, D, E and F.

Disconnector #3: This disconnector feeds substation "WM2," located on the second floor. It has a 200 A fuse.

Supply voltage quality has become an important consideration in recent years due to the increase in sensitive loads, such as electronically controlled equipment. [John, 2010]

Results

Disconnector #3: This disconnector feeds substation "WM2," located on the second floor. It has a 200 A fuse.

Supply voltage quality has become an important consideration in recent years due to the increase in sensitive loads, such as electronically controlled equipment. [John, 2010]

ISSN: 2523-2517
RENIECYT: 1702902

Journal Electrical Engineering 9[21]1-5: e4921105
Article

Box 3

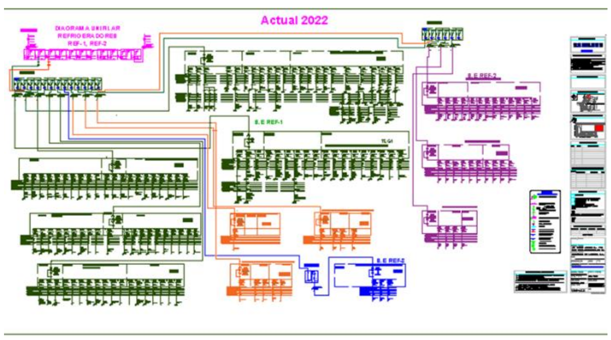


Figure 3
Electrical substation ref
Source: Own elaboration

Information was collected from each of the switches in the substations. To do this, the main switchboards were opened to measure current, verify conductor gauges, determine switch models, determine connection types, determine lengths and types of conduits, and perform visual inspections of the component status.

Box 4

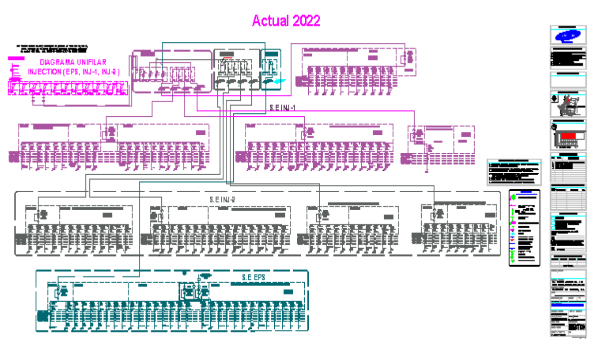


Figure 4
Electrical substation ref
Source: Own elaboration

Checking for variations in the information provided within the single-line diagrams and floor data, as well as identifying new equipment and removing information from breakers in the "free" state, adding new, useful information to complement the power diagrams. Hazards include risks and opportunities, and these terms relate to the unknown. Once the unknown is eliminated, the problem is no longer a safety issue. [Plata T. M., 2007]

To measure neutral and ground wires, surveys were conducted throughout the plant, checking the secondary power panels for ease and safety, as it was difficult to locate the conduit and the location to which it led within the substation panels.

Box 5

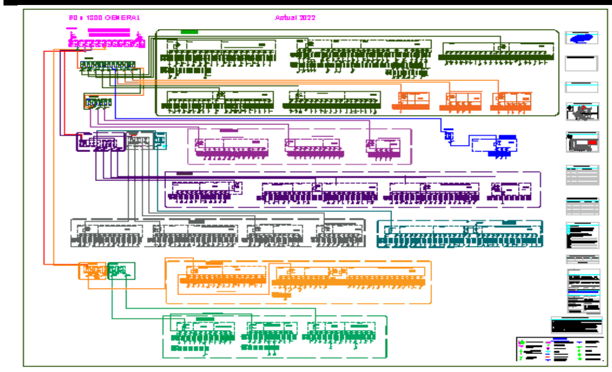


Figure 5
General one-line diagram
Source: Own elaboration

Availability of Data and Materials

For the analysis and evaluation of the safety, operation, and maintenance conditions of the main substation and the branch substations, the following technical information and relevant materials are available:

Technical data on electrical protections: Records are kept of the types of protection implemented, including overcurrent, differential, and distance protection, as well as the transformers' own systems, including thermal, pressure, and oil level protection [Harper, 2010]. This information allows for a functional analysis of the system in the face of different types of faults.

Single-line diagrams and electrical schematics: Electrical drawings are available for substations "WM1" and "WM2," including underground and overhead conduit routes, load distribution, and the location of breakers, disconnectors, and electromagnetic switches. Records are also kept of grounding connections, fuses, and busbars.

Equipment and Materials Specifications:

2000 kVA transformers, 34.5 kV to 380 V.

Overhead transmission conductors: 4/0 AWG ACSR, approximately 900 m long.

Distribution conductors: 1/0 AWG-XLP and 500 kcmil.

SIEMENS TDG1 [3200 A] and TDG2 [1200 A] electromagnetic transformers.

Protection fuses: 50 A and 200 A.

ISSN: 2523-2517
RENIECYT: 1702902

Rosas-Ortiz, Lenin Jacobo, Molina-García, Moises, Fuentes-Ramos, Francisco and Díaz-Cogco, Jonathan. [2025]. Implementation of single-line diagrams for an electrical substation Ref. Journal Electrical Engineering. 9[21]1-5: e4921105.
https://doi.org/10.35429/JEE.2025.9.21.4.1.5

Declarations

Conflicts of Interest

The authors declare no conflicts of interest. They have no known competing financial interests or personal relationships that could have influenced the submitted article.

Author's Contribution

Rosas-Ortiz, Lenin J.: Performed the transmission calculations.

Molina-García, Moises: Structured the voltage systems;

*Fuentes-Ramos, Francisco J: C*reated the single-line diagrams;

Díaz-Cogco, Jonathan: Analyzed the system and performed general revisions.

Funding

Funding was provided by the authors themselves.

Acknowledgments

We would like to thank Eng. Azael Cortés Peralta for his support in collecting data in the study area. We thank the National Institute of Technology of Mexico, specifically the Huatusco Higher Technological Institute, through its Electromechanical and Industrial Engineering educational program, for funding this research. We thank Dr. Lenin J. Rosas Ortiz for conducting the surveys. We thank Professor Francisco J. Fuentes Ramos for performing the calculations. We thank Professor Moises Molina García for his assistance with the writing.

Abbreviations

TC´S	CTs Current Transformers
EPP	PPE Personal Protective Equipment
SF6	SF6 Sulfur Hexafluoride
ACSR	ACSR Aluminum Conductor Steel Reinforced

Conclusions

At the end of this project, there is a perspective, as well as a broader vision in terms of systems, electrical equipment and updating of single-line diagrams.

Since it was possible to provide a solution to the problem that the company has, fulfilling each of the objectives set, from the collection of information in the field, the design of the single-line diagrams, as well as their updating, subsequently based on all this data and with the experiences obtained, the correction and update of the circuits of each of the substations was carried out.

From the above, we conclude that updating the single-line diagrams allows us to determine the accuracy of the results obtained in the field, since it facilitates a quick, clear, and concise understanding of the location of the circuits in each of the substations.

If we understand our electrical system, we'll know when it's operating with the quality and safety required to safeguard the integrity of people and physical facilities. We'll also be able to address any emergency demands or quality of service, and determine whether additional load increases and load relocation are possible.

References

Básic

David Rieske, R. A. [2012]. *Industrial safety and health dministration.* México: Thonson .
Harper, G. E. [2010]. *Desing elements of electrical substations.* México : Limusa.

Supports

John, S. W. [2010]. Power Systems Analysis . México : Graw Hill.

Plata, E. A. [2010]. Grounding systems: desinged with IEE-80 and evaluated with MEF. Bogotá: Universidad Nacional de Colombia . https://repositorio John, S. W. [2010]. *Power Systems Analysis* . México : Graw Hill.

Plata, E. A. [2010]. *Grounding systems: desinged with IEE-80 and evaluated with MEF.* Bogotá: Universidad Nacional de Colombia

Differences

Plata, T. M. [2007]. *Geometric design of platform and access to San Juan electrical substation IV region.*

ISSN: 2523-2517
RENIECYT: 1702902

[[Title in TNRoman and Bold No. 14 in English and Spanish]

Surname, Name 1st Author*[a], Surname, Name 1st Co-author[b], Surname, Name 2nd Co-author[c] and Surname, Name 3rd Co-author[d] [No.12 TNRoman]

[a] Affiliation institution, Researcher ID, ORC ID, SNI-SECIHTI ID or CVU PNPC [No.10 TNRoman]
[b] Affiliation institution, Researcher ID, ORC ID, SNI-SECIHTI ID or CVU PNPC [No.10 TNRoman]
[c] Affiliation institution, Researcher ID, ORC ID, SNI-SECIHTI ID or CVU PNPC [No.10 TNRoman]
[d] Affiliation institution, Researcher ID, ORC ID, SNI-SECIHTI ID or CVU PNPC [No.10 TNRoman]

All ROR-Clarivate-ORCID and SECIHTI profiles must be hyperlinked to your website.
Prot- University of South Australia • 7038-2013• 0000-0001-6442-4409 • 416112

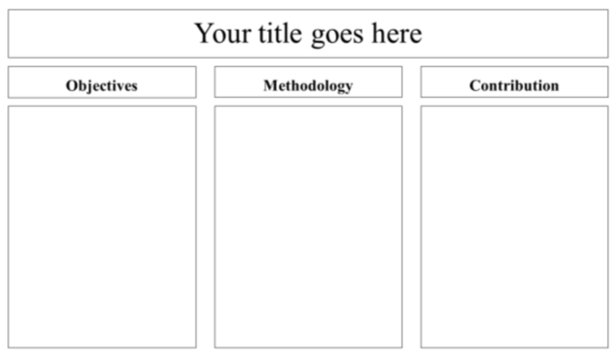
SECIHTI classification:
https://marvid.org/research_areas.php [No.10 TNRoman]
Area:
Field:
Discipline:
Subdiscipline:

DOI: https://doi.org/
Article History:
Received: [Use Only ECORFAN]
Accepted: [Use Only ECORFAN]
Contact e-mail address:
* ✉ [example@example.org]

Abstract [In English]
Must contain up to 150 words
Graphical abstract [In English]

Authors must provide an original image that clearly represents the article described in the article. Graphical abstracts should be submitted as a separate file. Please note that, as well as each article must be unique. File type: the file types are MS Office files.No additional text, outline or synopsis should be included. Any text or captions must be part of the image file. Do not use unnecessary white space or a "graphic abstract" header within the image file.

Abstract [In Spanish]
Must contain up to 150 words
Graphical abstract [In Spanish]



Authors must provide an original image that clearly represents the article described in the article. Graphical abstracts should be submitted as a separate file. Please note that, as well as each article must be unique. File type: the file types are MS Office files.No additional text, outline or synopsis should be included. Any text or captions must be part of the image file. Do not use unnecessary white space or a "graphic abstract" header within the image file.

Keywords [In English]
Indicate 3 keywords in TNRoman and Bold No. 10

Keywords [In Spanish]
Indicate 3 keywords in TNRoman and Bold No. 10

Citation: Surname, Name 1st Author, Surname, Name 1st Co-author, Surname, Name 2nd Co-author and Surname, Name 3rd Co-author. Article Title. Journal of Electrical Engineering. Year. V-N: Pages [TN Roman No.10].

Introduction

Text in TNRoman No.12, single space.

General explanation of the subject and explain why it is important.

What is your added value with respect to other techniques?

Clearly focus each of its features.

Clearly explain the problem to be solved and the central hypothesis.

Explanation of sections Article.

Development of headings and subheadings of the article with subsequent numbers

[Title No.12 in TNRoman, single spaced and bold]

Products in development No.12 TNRoman, single spaced.

Including figures and tables-Editable

In the article content any table and figure should be editable formats that can change size, type and number of letter, for the purposes of edition, these must be high quality, not pixelated and should be noticeable even reducing image scale.

[Indicating the title at the bottom with No.10 and Times New Roman Bold]

Box

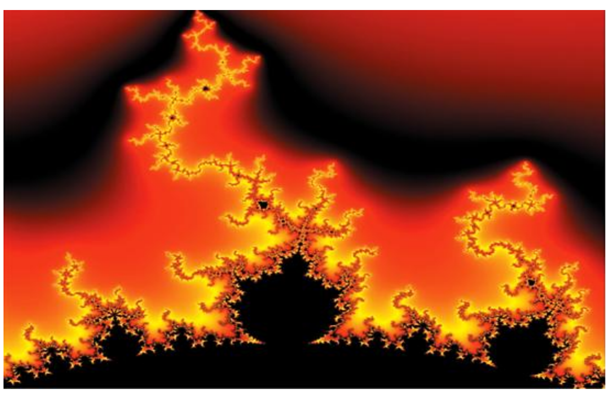


Figure 1
Title [Should not be images-everything must be editable]

Source [in italic]

Box

Table 1
Title [Should not be images-everything must be editable]

Source [in italic]

<u>The maximum number of Boxes is 10 items</u>

For the use of equations, noted as follows:

$$Y_{ij} = \alpha + \sum_{h=1}^{r} \beta_h X_{hij} + u_j + e_{ij} \qquad [1]$$

Must be editable and number aligned on the right side.

Methodology

Develop give the meaning of the variables in linear writing and important is the comparison of the used criteria.

Results

The results shall be by section of the article.

Conclusions

Clearly explain the results and possibilities of improvement.

Annexes

Tables and adequate sources.

<u>The international standard is 7 pages minimum and 14 pages maximum.</u>

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

ISSN 2523-2517

Author contribution

Specify the contribution of each researcher in each of the points developed in this research.

Prot-

Benoit-Pauleter, Gerard: Contributed to the project idea, research method and technique.

Availability of data and materials

Indicate the availability of the data obtained in this research.

Funding

Indicate if the research received some financing.

Acknowledgements

Indicate if they were financed by any institution, University or company.

Abbreviations

List abbreviations in alphabetical order.

Prot-

ANN	Artificial Neural Network

References

Use APA system. Should not be numbered, nor with bullets, however if necessary numbering will be because reference or mention is made somewhere in the Article.

Use the Roman alphabet, all references you have used should be in Roman alphabet, even if you have cited an article, book in any of the official languages of the United Nations [English, French, German, Chinese, Russian, Portuguese, Italian, Spanish, Arabic], you should write the reference in Roman alphabet and not in any of the official languages.

Citations are classified the following categories:

Antecedents. The citation is due to previously published research and orients the citing document within a particular scholarly area.

Basics. The citation is intended to report data sets, methods, concepts and ideas on which the authors of the citing document base their work.

Supports. The citing article reports similar results. It may also refer to similarities in methodology or, in some cases, to the reproduction of results.

Differences. The citing document reports by means of a citation that it has obtained different results to those obtained in the cited document. This may also refer to differences in methodology or differences in sample sizes that affect the results.

Discussions. The citing article cites another study because it is providing a more detailed discussion of the subject matter.

The URL of the resource is activated in the DOI or in the title of the resource.

Prot-

Mandelbrot, B. B. [2020]. Negative dimensions and Hölders, multifractals and their Hölder spectra, and the role of lateral preasymptotics in science. Journal of Fourier Analysis and Applications Special. 409-432.

Intellectual Property Requirements for editing:

- Authentic Signature in Color of Originality Format Author and Coauthors.
- Authentic Signature in Color of the Acceptance Format of Author and Coauthors.
- Authentic Signature in blue color of the Conflict of Interest Format of Author and Co-authors.

Reservation to Editorial Policy

Journal Electrical Engineering reserves the right to make editorial changes required to adapt the Articles to the Editorial Policy of the Research Journal. Once the Article is accepted in its final version, the Research Journal will send the author the proofs for review. ECORFAN® will only accept the correction of errata and errors or omissions arising from the editing process of the Research Journal, reserving in full the copyrights and content dissemination. No deletions, substitutions or additions that alter the formation of the Article will be accepted.

Code of Ethics - Good Practices and Declaration of Solution to Editorial Conflicts

Declaration of Originality and unpublished character of the Article, of Authors, on the obtaining of data and interpretation of results, Acknowledgments, Conflict of interests, Assignment of rights and Distribution

The ECORFAN-Mexico, S.C. Management claims to Authors of Articles that its content must be original, unpublished and of Scientific, Technological and Innovation content to be submitted for evaluation.

The Authors signing the Article must be the same that have contributed to its conception, realization and development, as well as obtaining the data, interpreting the results, drafting and reviewing it. The Corresponding Author of the proposed Article will request the form that follows.

Article title:

– The sending of an Article to Journal Electrical Engineering emanates the commitment of the author not to submit it simultaneously to the consideration of other series publications for it must complement the Format of Originality for its Article, unless it is rejected by the Arbitration Committee, it may be withdrawn.

– None of the data presented in this article has been plagiarized or invented. The original data are clearly distinguished from those already published. And it is known of the test in PLAGSCAN if a level of plagiarism is detected Positive will not proceed to arbitrate.

– References are cited on which the information contained in the Article is based, as well as theories and data from other previously published Articles.

– The authors sign the Format of Authorization for their Article to be disseminated by means that ECORFAN-Mexico, S.C. In its Holding Republic of Peru considers pertinent for disclosure and diffusion of its Article its Rights of Work.

– Consent has been obtained from those who have contributed unpublished data obtained through verbal or written communication, and such communication and Authorship are adequately identified.

– The Author and Co-Authors who sign this work have participated in its planning, design and execution, as well as in the interpretation of the results. They also critically reviewed the paper, approved its final version and agreed with its publication.

– No signature responsible for the work has been omitted and the criteria of Scientific Authorization are satisfied.

– The results of this Article have been interpreted objectively. Any results contrary to the point of view of those who sign are exposed and discussed in the Article.

Copyright and Access

The publication of this Article supposes the transfer of the copyright to ECORFAN-Mexico, S.C. in its Holding Republic of Peru for its Journal Electrical Engineering, which reserves the right to distribute on the Web the published version of the Article and the making available of the Article in This format supposes for its Authors the fulfilment of what is established in the Law of Science and Technology of the United Mexican States, regarding the obligation to allow access to the results of Scientific Research.

Article Title:

Name and Surnames of the Contact Author and the Co-authors	Signature
1.	
2.	
3.	
4.	

Principles of Ethics and Declaration of Solution to Editorial Conflicts

Editor Responsibilities

The Publisher undertakes to guarantee the confidentiality of the evaluation process, it may not disclose to the Arbitrators the identity of the Authors, nor may it reveal the identity of the Arbitrators at any time.

The Editor assumes the responsibility to properly inform the Author of the stage of the editorial process in which the text is sent, as well as the resolutions of Double-Blind Review.

The Editor should evaluate manuscripts and their intellectual content without distinction of race, gender, sexual orientation, religious beliefs, ethnicity, nationality, or the political philosophy of the Authors.

The Editor and his editing team of ECORFAN® Holdings will not disclose any information about Articles submitted to anyone other than the corresponding Author.

The Editor should make fair and impartial decisions and ensure a fair Double-Blind Review.

Responsibilities of the Editorial Board

The description of the peer review processes is made known by the Editorial Board in order that the Authors know what the evaluation criteria are and will always be willing to justify any controversy in the evaluation process. In case of Plagiarism Detection to the Article the Committee notifies the Authors for Violation to the Right of Scientific, Technological and Innovation Authorization.

Responsibilities of the Arbitration Committee

The Arbitrators undertake to notify about any unethical conduct by the Authors and to indicate all the information that may be reason to reject the publication of the Articles. In addition, they must undertake to keep confidential information related to the Articles they evaluate.

Any manuscript received for your arbitration must be treated as confidential, should not be displayed or discussed with other experts, except with the permission of the Editor.

The Arbitrators must be conducted objectively, any personal criticism of the Author is inappropriate.

The Arbitrators must express their points of view with clarity and with valid arguments that contribute to the Scientific, Technological and Innovation of the Author.

The Arbitrators should not evaluate manuscripts in which they have conflicts of interest and have been notified to the Editor before submitting the Article for Double-Blind Review.

Responsibilities of the Authors

Authors must guarantee that their articles are the product of their original work and that the data has been obtained ethically.

Authors must ensure that they have not been previously published or that they are not considered in another serial publication.

Authors must strictly follow the rules for the publication of Defined Articles by the Editorial Board.

The authors have requested that the text in all its forms be an unethical editorial behavior and is unacceptable, consequently, any manuscript that incurs in plagiarism is eliminated and not considered for publication.

Authors should cite publications that have been influential in the nature of the Article submitted to arbitration.

Information services

Indexation - Bases and Repositories

LATINDEX (Scientific Journals of Latin America, Spain and Portugal)
EBSCO (Research Database - EBSCO Industries)
RESEARCH GATE (Germany)
GOOGLE SCHOLAR (Citation indices-Google)
MENDELEY (Bibliographic References Manager)
HISPANA (Information and Bibliographic Orientation-Spain)

Publishing Services

Citation and Index Identification H
Management of Originality Format and Authorization
Testing Article with PLAGSCAN
Article Evaluation
Certificate of Double-Blind Review
Article Edition
Web layout
Indexing and Repository
ArticleTranslation
Article Publication
Certificate of Article
Service Billing

Editorial Policy and Management

1047 La Raza Avenue -Santa Ana, Cusco-Peru. Phones: +52 1 55 6159 2296, +52 1 55 1260 0355, +52 1 55 6034 9181; Email: contact@ecorfan.org www.ecorfan.org

ECORFAN®

Chief Editor
Quintanilla-Cóndor, Cerapio. PhD

Executive Director
Ramos-Escamilla, María. PhD

Editorial Director
Peralta-Castro, Enrique. MsC

Web Designer
Escamilla-Bouchan, Imelda. PhD

Web Diagrammer
Luna-Soto, Vladimir. PhD

Editorial Assistant
Rosales-Borbor, Eleana. BsC

Philologist
Ramos-Arancibia, Alejandra. BsC

Advertising & Sponsorship

(ECORFAN® Republic of Peru), sponsorships@ecorfan.org

Site Licences

03-2010-032610094200-01-For printed material ,03-2010-031613323600-01-For Electronic material,03-2010-032610105200-01-For Photographic material,03-2010-032610115700-14-For the facts Compilation,04-2010-031613323600-01-For its Web page,19502-For the Iberoamerican and Caribbean Indexation,20-281 HB9-For its indexation in Latin-American in Social Sciences and Humanities,671-For its indexing in Electronic Scientific Journals Spanish and Latin-America,7045008-For its divulgation and edition in the Ministry of Education and Culture-Spain,25409-For its repository in the Biblioteca Universitaria-Madrid,16258-For its indexing in the Dialnet,20589-For its indexing in the edited Journals in the countries of Iberian-America and the Caribbean, 15048-For the international registration of Congress and Colloquiums. financingprograms@ecorfan.org

Management Offices

1047 La Raza Avenue – Santa Ana, Cusco – Peru.

Journal Electrical Engineering

Photovoltaic energy manager with battery storage system for water pumping in isolated system

González-Aguayo, Mauricio Iván, Pérez-Hernández, Gustavo and Arroyo-Rodríguez, Francisco José

Tecnológico Nacional de México campus Cancún

Study of the discrete elements method in Lithium-ion batteries

Fernández-Gómez, Tomas, Fernández-Pérez, Vladimir Damian, Ramírez-Rodríguez, Ramón Rodolfo and Fernández-Pérez, Mitzy E

Tec. Nacional de México- Tecnológico de Orizaba

Kalman Filter: Optimal estimation in electrical, mechanical, and digital systems

Medécigo-Cabriales, Felipe A., Alaffita-Hernández, Francisco Alejandro, Colorado-Garrido, Dario and Escobedo-Trujillo, Beatris Adriana

Universidad Veracruzana

Implementation of single-line diagrams for an electrical substation Ref

Rosas-Ortiz, Lenin Jacobo, Molina-García, Moises, Fuentes-Ramos, Francisco and Díaz-Cogco, Jonathan

Tecnológico Nacional de México - Instituto Tecnológico Superior de Huatusco

2 5 2 3 2 5 1 7

ISSN 2523-2517

www.ecorfan.org