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CERTIFICATE OF ATTENDANCE

This is to certify that the paper:

Extended Jiles Atherton Model for Frequency Analysis of Magnetic Hysteresis

(Paper ID: 33)

Authored by **Dafri Mourad, Ladjimi Abdelaziz, Naidji Mourad, Tourab Wafa and Ksentini Abdelhamid**, was presented at the **ICEEA'25** conference.

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Extended Jiles–Atherton Model for Frequency Analysis of Magnetic Hysteresis

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Abstract. This study suggests an enhancement of the Jiles–Atherton model for simulating magnetic hysteresis in ferromagnetic materials by integrating the frequency effect into the model parameters. Utilizing experimental data from a MnZn ferrite toroidal core exposed to rapid magnetic fields, the model parameters are refined through the Particle Swarm Optimization (PSO) technique and adjusted for frequency dynamics. This method makes it possible to model hysteretic behavior in a realistic way, especially at high frequencies, where phase shift and hysteresis loop broadening effects are most important. The results have been experimentally validated and show a good match with the extended Jiles–Atherton model. This opens up new possibilities for use in high-frequency electrical engineering devices.

Keywords: Jiles–Atherton, magnetic hysteresis, particle swarm optimization, ferrite, frequency.

1 Introduction

Magnetic hysteresis is a natural process that happens in ferromagnetic materials and has a big effect on how well electrical devices like motors, transformers, and power electronics work. So, accurate hysteresis modeling is very important for figuring out core losses and thermal effects [1-2]. The static Jiles–Atherton (JA) model is one of the most popular methods because it strikes a good balance between being physically relevant and being easy to compute [3]. The classical static JA model, however, has serious problems when it comes to fast magnetic excitations because it doesn't take into account how hysteresis loops behave differently at different frequencies and the dynamic losses that come from this [4-5].

To address these limitations, this study enhances the JA model by explicitly integrating frequency effects into its parameters. The suggested method is based on experimental data taken from MnZn ferrite cores when they were quickly excited by a magnetic field. A Particle Swarm Optimization (PSO) technique is used to find model parameters [6], which makes sure that the model can adapt accurately to changing conditions. Experimental validation shows that the extended model accurately reproduces phase lag and hysteresis loop broadening at high frequencies. This makes it a reliable tool for high frequency electromagnetic applications and for estimating magnetic loss.

2 The Jiles Atherton model

Jiles Atherton (JA) model [3] states that the sum of the contributions of the irreversible (M_{irr}) and reversible (M_{rev}) magnetization components can be used to describe the overall magnetization of a ferromagnetic material.

$$\mathrm{M} = \mathrm{M_{irr}} + \mathrm{M_{rev}} \tag{1}$$

The combination of the walls' reversible translation and rotation in ferromagnetic materials called the reversible component. However, the irreversible component stands for the magnetic domains' irreversible displacement. It is possible to develop the differential equation that describes how magnetization depends on the magnetic field as.

$$M_{rev} = c(M_{an} - M_{irr}) \tag{2}$$

$$M = M_{an} - k\,\delta\,\frac{dM_{irr}}{dH_e} \tag{3}$$

where Man is the Anhysteretic magnetization, which corresponds to an ideal, reversible and thermodynamically balanced state, without hysteretic losses.

Where $H_e = H + \alpha M$ is the effective field that accounts for the domain interactions, k parameter is linked to the coercitive field, c is the reversibility coefficient, and δ parameter $\delta = +1$ when $\frac{\mathrm{dH}}{\mathrm{dt}} > 0$ and $\delta = -1$ when $\frac{\mathrm{dH}}{\mathrm{dt}} < 0$ [3].

The following is an expression for the differential susceptibility based on the JA model.

$$\frac{dM}{dH} = \frac{(1-c)\frac{dM_{irr}}{dH_e} + c\frac{dM_{an}}{dH_e}}{1-\alpha c\frac{dM_{an}}{dH_e} - \alpha(1-c)\frac{dM_{an}}{dH_e}} \tag{4}$$

The JA model has already been extended to account for magnetoelastic effects [7–8], anisotropy [9], and temperature [10–15]. Previous attempts to include frequency effects [16] were mainly based on coupling the JA model with Chua's mathematical framework. In addition, Jiles proposed another extension of the JA model in [4], offering a different approach to describe frequency-dependent hysteresis behavior. In the present work, we propose a new extension by directly incorporating the frequency effect into the parameters of the static JA model.

3 Integration of the frequency effect in the static JA model

The frequency effect of the exciting magnetic field is integrated into the static Preisach model using an adapted model of the parameter k and c.

3.1 Determination of the model parameters as a function of the frequency

From an experimentally measured hysteresis loop, the PSO optimization method was applied to identify the parameters of the static Jiles-Atherton model. For each excitation frequency (500–2500 Hz), the five model parameters (a, k, α, c, Ms) were determined. The results, presented in a table 1, highlight the evolution of these parameters with frequency, allowing for an analysis of the dynamic effects on the hysteretic behavior of the material.

Table 1. Parameters identified with the PSO method.

f (Hz)	a	k	Erreur (ε)
500	39.4161	0.3643	3.1677e-05
1000	45.0284	0.3643	3.3535e-05
1500	51.8785	0.3643	1.7470e-05
2000	57.0124	0.3643	2.8239e-04
2500	63.2557	0.3643	7.2635e-05

The effects of frequency can be incorporated into the Jiles-Atherton model by introducing a frequency dependence into certain parameters, particularly a and k. The other model parameters, such as Ms = 534621.0588, c = 0.3643, and α = 0.0004, are considered constant.

3.2 Introduction de la loi du comportement fréquentiel dans les paramètres

By making the parameters a(f) and k(f) frequency-dependent, it becomes possible to account for part of the dynamic effects while maintaining a stable and simple model for simulation. In this work, their frequency evolution was identified and modeled from experimental measurements. The resulting laws modify the static Jiles-Atherton model, overcoming the limitation of constant parameters and improving the representation of the material's dynamic behavior.

The evolution of the parameters a and k as a function of frequency can be modeled by equations (5) and (6), which we propose below:

$$a(f) = A\sqrt{f}\,.\,e^{Bf} + C \tag{5}$$

$$k(f) = D\sqrt{f}\,.\,e^{Ef} + F \tag{6}$$

The analysis of the variation of parameters *a* and *k* with frequency, presented in Figure 1, enabled the extraction of the constants A, B, C, D, E, and F required for the proposed model.

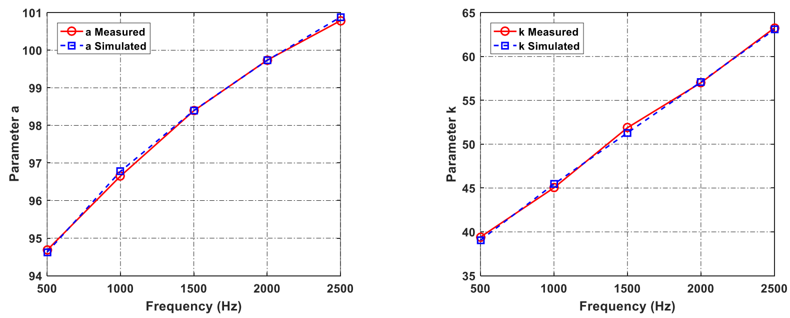
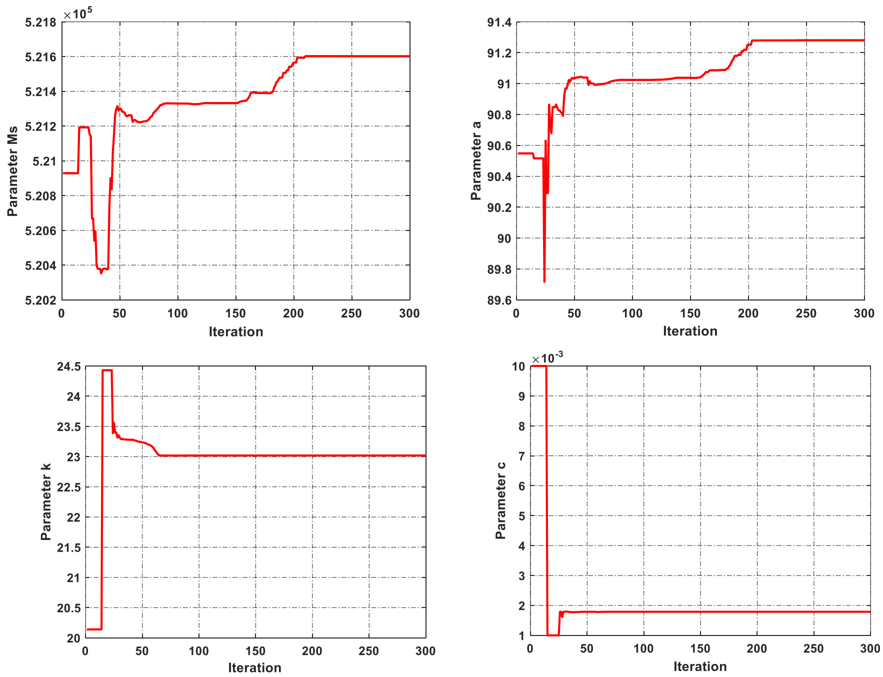


Fig. 1. Frequency-dependent behavior of parameters a and k with A = 0.242107, B= -0.00001294, C = 89.315148, D = 0.465738, E = 0.00015627 and F = 26.928752.

4 Validation expérimentale de l'extension apportée au modèle

At an excitation frequency of 500 Hz, the five parameters a, k, α, c, and Ms were identified and optimized using the PSO algorithm. These optimized values provide a baseline for studying the frequency dependence of the parameters and for evaluating the dynamic effects on the hysteretic behavior of the material.



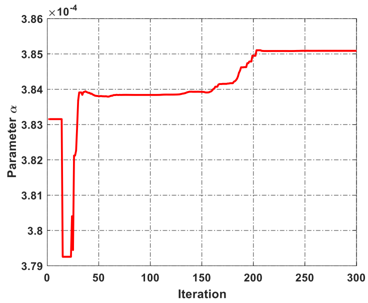


Fig. 2. Evolution of the optimization process of the parameters Ms, a, k, c and α.

Figure 3 illustrates the variation of the mean squared error ε between the hysteresis loops generated by the Jiles–Atherton model and the experimental data obtained from the descending branch of the measured cycle.

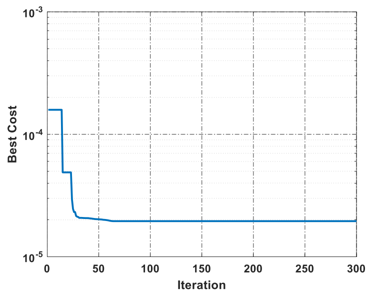
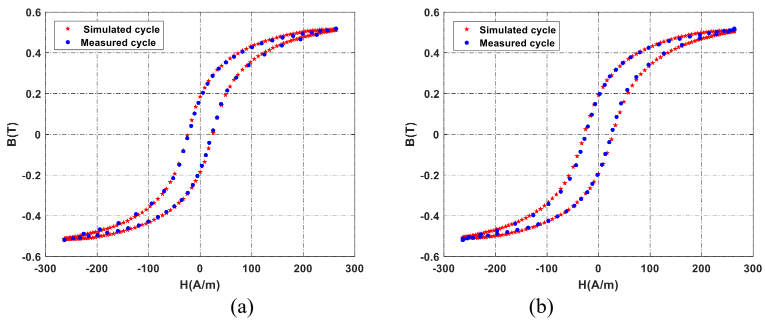
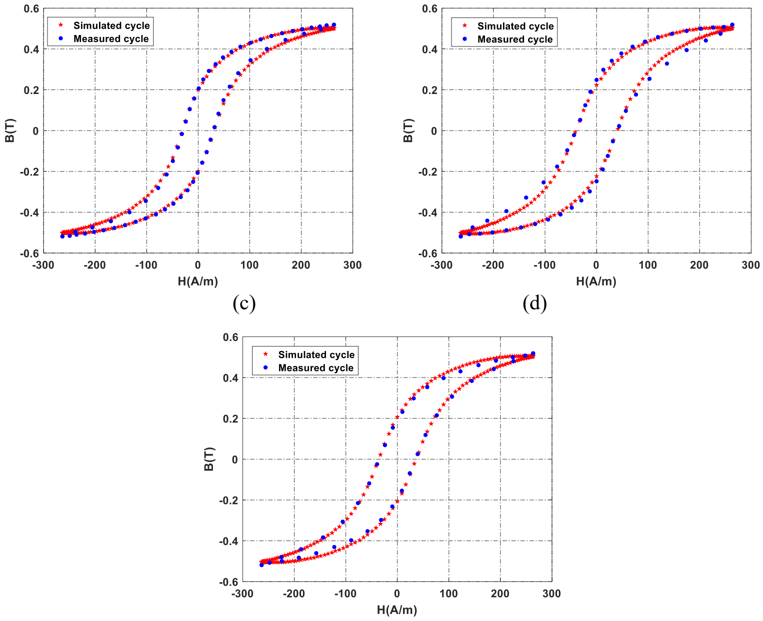


Fig. 3. Convergence curve of the optimization process using PSO.

Figure 4 presents the hysteresis loops obtained experimentally and through simulation for various frequencies.





(e)

Fig. 3. Comparison between the measured and simulated hysteresis loops at frequencies: (a) 500 Hz, (b) 1000 Hz, (c) 1500 Hz (d) 2000 Hz and (e) 2500 Hz.

The superposition of the measured and simulated hysteresis loops, for excitation frequencies ranging from 500 Hz to 2500 Hz, reveals an excellent agreement. The extended Jiles–Atherton model accurately reproduces the loop shapes as well as key parameters such as the coercive field Hc, the remanent induction Br, and the saturation induction Bs. These results confirm the accuracy and robustness of the proposed extension in representing the dynamic behavior of the material.

Table 2 presents a comparison between the experimental and simulated values of the saturation induction Bs, the remanent induction Br and the coercive field Hc.

Table 2. Evolution of magnetic quantities as a function of frequency.

Fréquence (Hz)	**500**	**1000**	**1500**	**2000**	**2500**
Bs (T) Mesures	0.518	0.518	0.518	0.518	0.518
Bs(T) Simulations	0.5133	0.5068	0.5012	0.504	0.5019
Erreur (%)	0.91	2.16	3.24	2.70	3.11
Br(T) Mesures	0.1741	0.1859	0.2032	0.1897	0.2471
Br(T) Simulations	0.1861	0.1927	0.1995	0.2066	0.2233
Erreur (%)	6.68	3.66	1.82	8.90	9.63
Hc(A/m) Mesures	22.6419	24.8798	29.417	35.1932	40.1763
Hc(A/m) Simulation	24.1758	27.8029	31.0845	36.1671	40.0159
Erreur (%)	6.77	11.74	5.67	2.77	0.40

The comparative analysis between the measured and simulated magnetic quantities as a function of frequency (500 to 2500 Hz) highlights the effectiveness of the extended Jiles–Atherton model in reproducing the dynamic behavior of the studied material. The simulated values of the saturation induction (Bs) generally match the experimental values, with an error consistently below 3.24%, thus validating the predictive capability of the model with respect to magnetic saturation, although moderate deviations appear at higher frequencies. A more pronounced variability is observed for the remanent induction (Br), with the error ranging from 1.82% to 9.63%, reflecting the sensitivity of Br to dynamic phenomena not fully captured, particularly internal relaxation losses. In contrast, the model reproduces the coercive field (Hc) with high accuracy, especially at high frequencies where the error is minimal (0.40% at 2500 Hz). This performance results from incorporating frequency-dependent parameters, such as a(f) and k(f), into the model, which significantly improves the representation of magnetization delay and the tracking of the hysteresis cycle.

5 Conclusion

This research has demonstrated the relevance of integrating the frequency effect into the static Jiles–Atherton model for MnZn ferrite. Through rigorous parameter identification using PSO optimization applied to hysteresis loops measured at different frequencies, a frequency-dependent law was introduced for the essential parameters. Experimental validation based on the comparison between simulated and measured loops from 500 to 2500 Hz confirms the accuracy of the modified model, which faithfully reproduces key characteristics such as coercivity, remanence, and saturation. This study highlights the capability of the extended model to capture magnetic dynamic effects in MnZn ferrite, thereby providing a solid foundation for the modeling and optimization of electrical devices subjected to fast excitations.

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The International Conference on Electrical Engineering and its Applications (ICEEA) is organized by the Electrical Engineering Laboratory (LGEG), with the collaboration of the faculty of Science and Technology and the University 8 may 1945, Guelma, Algeria. The ICEEA conference aims to become an annual event in the field of the electrical engineering and related applications. It is intended to gather scholars from all over the world to present advances in the relevant fields and to offer an environment conducive to exchanging ideas and information.

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Instructions for authors:

Authors are invited to submit original contributions (written in English, minimum of 4 pages, maximum of 6 pages in PDF format). Please use the official ICEEA'25 template to prepare the manuscript. Submissions will be made using the CMT Microsoft system:
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Submission Deadline: September 10, 2025
Notification of Acceptance: October 1, 2025
Camera-Ready Submission: October 20, 2025
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The International Conference on Electrical Engineering and its Applications

THE INTERNATIONAL CONFERENCE ON ELECTRICAL ENGINEERING AND ITS APPLICATIONS

November 16 - 17, 2025 - Guelma, Algeria

ICEEA'25 Program

Day 01: Sunday, November 16, 2025	
08:00 – 08:30	**Registration**
08:30 – 09:00	**Opening Ceremony**
09:00 – 10:30	**Keynote Speakers**
	Keynote 1: ***Neural Networks for Condition Monitoring and Fault Detection in Industrial Systems.*** **Prof. Serhat Şeker** | Istanbul Technical University (ITU) Electrical and Electronics Engineering Faculty, Istanbul, Turkey.
	Keynote 2: ***Tidal Stream Power on the Rise: Grid Integration and Storage Solutions for Marine Renewable Energy.*** **Prof. Mohamed Benbouzid** | University of Brest, Institut de Recherche Dupuy de Lôme, Brest, France.
	Keynote 3: ***Renewable Energy Trends Opportunities and Environmental Footprint Challenges.*** **Prof. Hocine Labar** | Badji Mokhtar-Annaba University, Algeria.
10:30 – 11:00	**Coffee Break**
11:00 – 13:00	**Parallel sessions**
	Thematic Session A: ***Applications of Artificial Intelligence and Machine Learning.*** **(Conference room)** Chairs: Pr. Moussaoui Abdelkrim and Pr. Nemissi Mohamed
	Merdaci Anfel, "Development of an Intelligent Warning System for Forest Fire Prediction and Prevention", University of Khenchela.
	Benhamza Karima, "An Efficient Intrusion Detection System for Enhancing Security in IoMT Environments", University of Guelma.
	Chaieb Houcine Ayoub, "Trajectory Tracking for Multi-UAV Control of Cable-Suspended Payload", EMP Algiers.

	Thematic Session B: ***Power Systems and Smart Grids.*** **(Room 1)** Chairs: Pr. Labar Hocine and Pr. Lemzadmi Ahcene
	Bezzar Nour El Houda, "Household Electricity Consumption Forecasting Using XGBoost Time Series Models", University of Tebessa.
	Gouaidia Said, "Optimal series capacitor compensation for increase transmission line loadability", University of Guelma.
	Thematic Session C: ***Renewable Energy, Storage and Sustainable Technologies.*** **(Room 2)** Chairs: Pr. Bahi Tahar and Pr. Dib Djalel
	Amiri Ahmed Faris, "Short-Term Solar Irradiance Forecasting Using LSTM Networks: A Case Study with Multi-Year Data", University of M'sila.
	Bensmara Ahlem, "Grid Connected DFIG-Based Wind System Using Vector Control Technique", University of Jijel.
13:00 – 14:00	**Lunch Break**
14:00 - 17:00	**Parallel sessions**
	Thematic Session E: ***High Voltage Engineering and Insulation.*** **(Conference room)** Chairs: Pr. Bayadi Abdelhafid and Pr. Nouri Hamou
	Guerroui Assia, "Modeling and Calculation of Breakdown voltage in SF6-N2 Using an Artificial Neural Network", University of Guelma.
	Moussaoui Aida, "Discharge Characteristics of Corona Charged Compact Granular Layers", University of Guelma.
	Bouchelkha Abdelhafid, "Sizing a Corona Discharge System in a Coaxial Wire-Cylinder Configuration", University of Guelma.
	Alti Nadjim, "Dynamic Modeling of Flashover Phenomena on Polluted Insulator Surfaces", University of Sétif. (**Online**)
	Thematic Session B: ***Power Systems and Smart Grids.*** **(Room 1)** Chairs: Pr. Labar Hocine and Pr. Lemzadmi Ahcene
	Dine Mohamed, "Accurate Fault Location Algorithm for TCSC Compensated Transmission Line Connected to Wind Farms", University of Medea. (**Online**)
	Ouail Mohamed, "Optimal Energy Management of Distributed sources-based on PV and Energy Storage System (ESS)", University of Chlef. (**Online**)
	Thematic Session C: ***Renewable Energy, Storage and Sustainable Technologies.*** **(Room 2)** Chairs: Pr. Bahi Tahar and Pr. Dib Djalel
	Lakhdara Amira, "Model Predictive Energy Management and Control Strategy for a Solar–Hydrogen Hybrid Smart Microgrid", University of Annaba.
	Nabti Zineb, "Controlled Electrodeposition of MnO_2 for High-Performance Zn–MnO_2 Rechargeable Batteries", University of Guelma.

	Khelfa Omar, "Technical and Economic Comparison between Photovoltaic Pumping and Medium Voltage Grid Supply in Semi-Arid Areas", University of Djelfa. (**Online**)
	Tamer Emre, "Market-Integrated Approaches for Energy Affordability: Türkiye's Hybrid Strategy under the Renewable Transition", Akenerji Electricity Production, Istanbul, Turkey. (**Online**)
Day 02: Monday, November 17, 2025	
08:00 – 10:45	**Parallel sessions**
	Thematic Session C: ***Renewable Energy, Storage and Sustainable Technologies.*** **(Conference room)** Chairs: Pr. Bahi Tahar and Pr. Dib Djalel
	Azizi Amina, "Study on the Detection of Faults Related to Photovoltaic Installations", University of Annaba.
	Douakha Oussama, "Intelligent Energy Management of Electric Vehicles through Hybrid Battery–Supercapacitor Architecture", University of Guelma.
	Bourrich Youcef, "Impact of Experimental Conditions on SVM Classification of Photovoltaic Defects from I–V Curves", University of Guelma.
	Zerzouri Nora, "Modeling and Simulation of a Grid-Connected Photovoltaic System Using a Single-Stage Converter", University of Annaba. (**Online**)
	Thematic Session D: ***Signal Processing and Communications.*** **(Room 1)** Chairs: Pr. Babouri Abedesselam and Dr. Ghadjati Mohamed
	Elhachi Hana, "Performance Analysis of Unreliable Transport Protocols for Low-latency apps in VANET", University of Guelma.
	Bouhous Adil, "A robust encryption watermarking algorithm for speech messages", CRSTDLA, Algiers. (**Online**)
	Elhachi Hana, "Is QUIC a Viable Alternative to TCP for Video Streaming Applications in Vehicular Networks ? ", University of Guelma.
	Yahi Nour el houda, "Antenna Diversity and Relay Antenna Selection in Cooperative TH-UWB Systems Using Equalization Techniques", University of Sidi Bel Abbes. (**Online**)
	Thematic Session G: ***Electrical Machines and Drives.*** **(Room 2)** Chairs: Pr. Allag Hicham and Pr. Mendaci Sofiane
	Bachir Samia, "Influence of Soft Magnetic Material Properties on the Electromagnetic Characteristics of a Linear Induction Motor", University of Annaba.
	Hassina Ziou, "Analysis of the Behavior of a Piezoelectric Beam Actuator Using the Finite Element Method", CNERIB, Algiers. (**Online**)
	Dafri Mourad, "Extended Jiles Atherton Model for Frequency Analysis of Magnetic Hysteresis", University of Annaba. (**Online**)
10:45 – 11:00	**Coffee Break**

11:00 – 13:30	**Parallel sessions**
	Thematic Session G: ***Electrical Machines and Drives.*** **(Room 2)** Chairs: Pr. Allag Hicham and Pr. Mendaci Sofiane
	Nehal Ouassila, ”Sliding-Mode Assisted Direct Torque Control for Reliable Wind Turbine Operation”, University of Tebessa. (**Online**)
	Benamimour Tariq, “Finite element modeling of a hybrid Switched Reluctance Machine (Permanent Magnet SRM)”, University of Annaba. (**Online**)
	Hamdane Houssem, ”Vibration-Based Analysis for Fault Diagnosis of Unbalance and Misalignment Defects in Induction Machines”, University of Annaba. (**Online**)
	Khadar Saad, ”Improved Sensorless Method Based on Luenberger Observer of a 5-phase Permanent Magnet Synchronous Motor”, University of Djelfa. (**Online**)
	Thematic Session E: ***High Voltage Engineering and Insulation.*** **(Room 1)** Chairs: Pr. Bayadi Abdelhafid and Pr. Nouri Hamou
	Mouhoub Sarra, ”Prediction of the triboelectric charge of moving particles inside a metallic canalization”, University of Guelma.
	Bechkoura Hana, ”Modified Configuration of the Cylinder-Plate Electrostatic Separator for the Recovery of PVC and Aluminum Particles From Waste Electric Wires”, University of Guelma.
	Larba Mohammed, ”Experimental Study of Discharge Currents on the Surface of Polyvinyl Chloride PVC”, University of Bejaia
	Ait Yahia Abdellah Walid, ”Experimental Analysis of the Force of Attraction Exerted on Metal Particles Using an Electrostatic Actuator”, University of Sidi-Bel-Abbes. (**Online**)
	Thematic Session F: ***Power Electronics and Control Systems.*** (**Conference room**) Chairs: Pr. Omeiri Amar and Pr. Ladjimi Abdelaziz
	Malki abdallah, ”Control of a Single-Phase Unified Power Conditioner for Power Quality Enhancement: Experimental Validation”, University of bechar.
	Bahita Mohamed, ”Process Control by Modified State Feedback Based on Linearization Around an Operating Point”, University of Constantine.
	Khadar Saad, ”Improved Predictive Control for Permanent Magnet Synchronous Motors Using Backstepping Control”, University of Djelfa. (**Online**)
	Benhemine Asma, ”Performances of Sliding Mode Control of a DFIG Wind System based Indirect Matrix Converter”, University of Bechar. (**Online**)
	Attallah Faris, “Application of the GPBiCG(m, ℓ) Iterative Solver to Large-Scale Power System Analysis”, University of Bab Ezzouar. (**Online**)
13:30	**Closing and Lunch**