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Préface

Le 4 févriere 2025 a eu lieu la 5e édition de la journée des étudiant(e)s du GERAD, sous le thème de la transition énergétique. Le but de cet événement était de donner aux étudiant(e)s l'opportunité de présenter leurs projets à leurs pairs. Cet évènement, se tenant dans le cadre du Semestre thématique de l'hiver 2025 sous le thème de l'aide à la décision pour la transition énergétique, les étudiant(e)s ont sollicité des présentations en lien avec les questions énergétiques et environnementales.

Deux formats étaient offerts aux étudiant(e)s souhaitant présenter : 1) une présentation orale devant public (5-10 minutes) ou 2) une présentation par affiche. Ce cahier est une édition spéciale des Cahiers du GERAD présentant les résumés affiches.

Foreword

On February 4, 2025, the 5th edition of GERAD's Student Day took place, under the theme of energy transition. The aim of this event was to give students the opportunity to present their projects to their peers. Held as part of the Winter 2025 Thematic Semester on the theme of decision support for energy transition, students were asked to make presentations related to energy and environmental issues.

Two formats were offered to students wishing to present: 1) an oral presentation before an audience (5-10 minutes) or 2) a poster presentation. This is a special edition of Cahiers du GERAD presenting the poster abstracts.

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1 Metaheuristics and hyperheuristics for large-scale optimization of mining complexes

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Les Cahiers du GERAD

Abstract: *An industrial mining complex is an integrated value chain includes the excavation, transportation, processing, and distribution of mineral products as well as the storage of waste products. Critical sources of uncertainty include the characterization of the mineral deposits, commodity prices, equipment performance, and processing facility performance. To maximize long-term value of the mining complex, an optimization model is formulated, accounting for decisions in block extraction, material destination policy, downstream material flow, capital investments, and major operating modes. The size of the model, number of binary and integer variables, and the presence of non-linear transformations in the formulation make optimization with exact methods highly impractical. Metaheuristics have been used to provide good solutions in reasonable execution times. Hyperheuristics have extended these capabilities, using online learning to accelerate optimization. Algorithms amenable for parallel computing present opportunities to scale hardware and further improve optimization results while reducing execution times. The present work reviews these developments and explores how they can be combined for the application of optimizing mining complexes.*

Metaheuristics and Hyperheuristics for Large-Scale Optimization of Mining Complexes

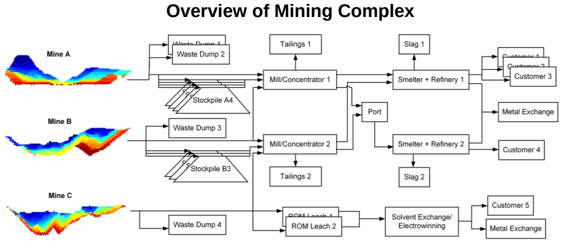
COSMO
Stochastic Mine Planning Laboratory

Liam Findlay & Roussos Dimitrakopoulos, McGill University

Background

- An industrial mining complex is an integrated value chain that includes the excavation, transportation, processing, and distribution of mineral products as well as the storage of waste products
- To maximize long-term value of the mining complex, an optimization model is formulated, accounting for all decisions simultaneously
- Capital investments are major decisions that have a significant impact on the outcome of the mining project
- Critical sources of uncertainty need to be considered in the inputs to manage risk; these can be quantified using conditional simulation
- A sophisticated solution approach is needed to handle the large optimization problem

Overview of Mining Complex



Sources of Uncertainty

- Geostatistical: distribution of key material properties (e.g. metal grades, grindability, minerology, material type,…)
- Geometallurgical: performance of processing facilities (e.g. comminution energy consumption, metal recovery, reagent consumption, tailings properties,…)
- Economic: commodity prices
- Equipment: availability, utilization, efficiency

Stochastic Integer Programming Formulation

Key Decision Variables

Mine block b in period t	$x_{bt} \in \{0,1\}$
Send cluster c to destination j in period t	$z_{cjt} \in \{0,1\}$
Send portion of material from i to j in period t, scenario s	$y_{ijts} \in [0,1]$
Number of CAPEX options k taken in period t	$w_{kt} \in \{0,1,2,\ldots\}$
Use operating mode a at process facility i in period t	$u_{iat} \in \{0,1\}$
Upward and downward deviations from production target h at location i in period t and scenario s	$d^+_{hits}, d^-_{hits} \geq 0$

Objective Function

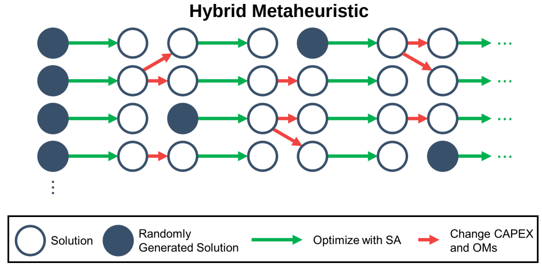
$$\max \underbrace{\frac{1}{|\mathbb{S}|}\sum_{s\in\mathbb{S}}\sum_{i\in\mathcal{N}}\sum_{h\in\mathbb{H}}\sum_{t\in\mathbb{T}} p_{hit}\cdot v_{hits}}_{\text{Discounted cashflow}} - \underbrace{\sum_{k\in\mathbb{K}}\sum_{t\in\mathbb{T}} p_{kt}\cdot w_{kt}}_{\text{CAPEX Costs}} - \underbrace{\sum_{i\in\mathcal{P}}\sum_{a\in\mathbb{A}_i}\sum_{t\in\mathbb{T}} p_{iat}\cdot u_{iat}}_{\text{Operating Mode Costs}}$$

$$-\underbrace{\frac{1}{|\mathbb{S}|}\sum_{s\in\mathbb{S}}\sum_{i\in\mathcal{N}}\sum_{h\in\mathbb{H}}\sum_{t\in\mathbb{T}}[c^+_{hit}\cdot d^+_{hits} + c^-_{hit}\cdot d^-_{hits}]}_{\text{Penalties}}$$

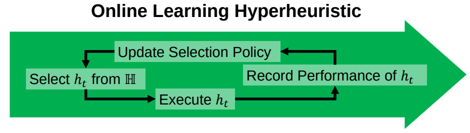
Solution Framework

- Number of (integer and binary) variables and nonlinear components in the formulation make exact solvers impossible
- Simulated Annealing provides a base to start developing a solution method for this problem
- CAPEX and operating mode decisions pose a challenge for perturbation-based metaheuristics because changing them requires many changes to other variables
- Idea 1: Always accept perturbations to CAPEX and operating mode decisions but make these tabu for a fixed duration afterwards
- Idea 2: Run multiple executions in parallel with different starting solutions to capitalize on hardware resources, taking the best single solution at the end
- Idea 3: Allow the executions to communicate when perturbing CAPEX and operating mode decisions, keeping or perturbing the best and discarding the worst solutions, creating an evolutionary algorithm with simulated annealing embedded into each generation
- Idea 4: Use online learning to improve heuristic selection during simulated annealing phase and mutation selection during the evolutionary phase to accelerate optimization performance

Hybrid Metaheuristic



Online Learning Hyperheuristic



2 Contextual stochastic optimization of industrial mining complexe

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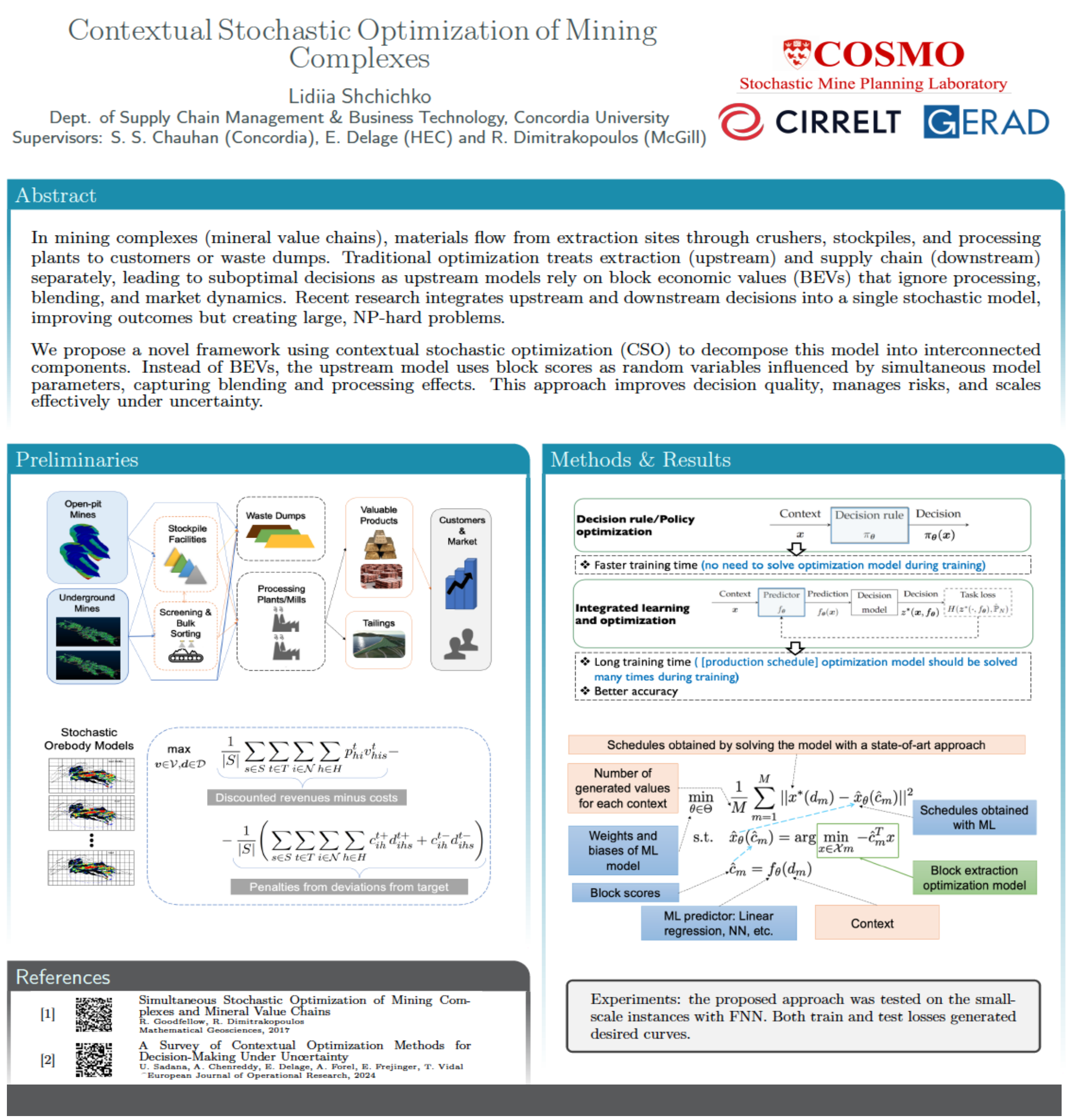
Abstract: *In mining complexes or mineral value chains, materials flow from extraction sites (mines) through crushers, stockpiles, waste dump and tailings, and processing plants to supply minerals to customers and market. New developments over the last decade have developed new advanced technologies for the simultaneous stochastic optimization of a mining complex, integrating upstream and downstream decisions into a single stochastic optimization model, that also manages the related supply (geological) and demand (market) uncertainties. This comprehensive approach addresses shared resources and operational interdependencies but results in large-scale, NP-hard problem that challenges existing solvers. To further tackle computational complexities, a novel framework leveraging contextual stochastic optimization is proposed to decompose the simultaneous stochastic model into interconnected upstream and downstream components. The proposed upstream model relies on pertinent block properties treated as random variables influenced by simultaneous model parameters, effectively capturing blending and processing activities. In particular, decision rules and end-to-end methods of contextual stochastic optimization are proposed. This framework enhances decision quality, manages risks, and offers a scalable solution for optimizing mining complexes under uncertainty.*



3 Simultaneous stochastic optimization of mining complexes: Integrating waste management and progressive reclamation with encapsulation

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Abstract: *Effective waste rock management is a crucial aspect of long-term planning of industrial mining complexes. When waste management is not considered during the optimization of the production schedule, it leads to an inaccurate assessment of the financial outcomes of the mining complex. This oversight can be especially costly when dealing with potentially acid-generating (PAG) waste rock, as it introduces the risk of significant treatment costs with rehabilitation, primarily due to acid rock drainage (ARD). Traditional practices don't optimize production schedules while addressing this risk and fail to integrate geological uncertainty so as to create a production schedule resilient to waste misclassification and uncertain supply of material extracted from the related mines. To prevent or mitigate ARD, proactive measures such as encapsulating PAG material with non-acid-generating (NAG) material are essential. Furthermore, stricter legislation reinforces the necessity to restore mining sites to an acceptable post-mining condition using ongoing reclamation to ensure environmental stability and reduce long-term liabilities. This work integrates waste management and progressive rehabilitation into the simultaneous stochastic optimization framework, employing gradual encapsulation of PAG material to promote progressive reclamation, thereby reducing long-term environmental and financial liabilities. Uncertainties in acid generation are addressed using geostatistical simulations of the rock's geochemical properties. A case study at a copper-gold mining complex demonstrates that incorporating waste management using progressive encapsulation has a minimal financial impact.*

Simultaneous Stochastic Optimization of Mining Complexes: Integrating Waste Management and Progressive Reclamation with Encapsulation

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Background

A block model represents a mineral deposit as a three-dimensional array. The sequence in which blocks are extracted from the ground significantly impacts the financial outcome of a mining complex. Additionally, destination policy decisions and downstream processing choices play a crucial role in determining the value of the final products sold to the market. This set of decisions controls which facility an extracted block is sent to and how material flows between them.

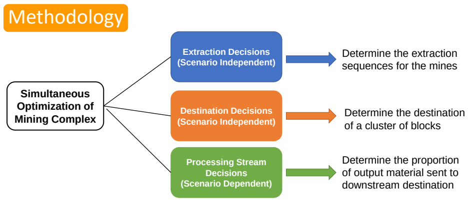
Uncertainties in the block model can lead to decisions with unpredictable results. In light of this, the problem is to make decisions resilient to uncertainty regarding which blocks to extract, in which period, where to send them, and how to control the flow of material between destinations to maximize the net present value (NPV) of the mine while respecting various constraints.

Introduction

Effective waste rock management is a crucial aspect of long-term mining planning. When waste management is not considered during the optimization of the production schedule, it leads to an inaccurate assessment of the financial outcomes of the mining complex. This oversight can be especially costly when dealing with potentially acid-generating (PAG) waste rock, as it introduces the risk of significant treatment costs with rehabilitation, primarily due to acid rock drainage (ARD).

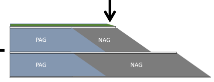
This work integrates waste management into a simultaneous stochastic optimization framework, employing gradual encapsulation of PAG material to promote progressive reclamation, thereby reducing long-term environmental and financial liabilities.

Methodology



A generalized two-stage stochastic optimization model is proposed by Goodfellow and Dimitrakopoulos (2016) to maximize the profit from product sales while minimizing deviations from production targets.

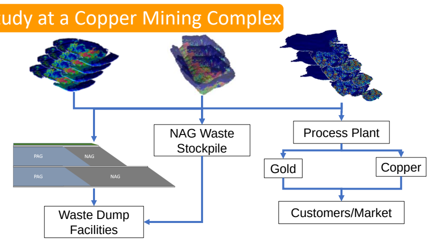
$$Max \frac{1}{\|\mathbb{S}\|}\sum_{t\in\mathbb{T}}\sum_{s\in\mathbb{S}}\sum_{a\in\mathbb{A}} p_{a,t}v_{a,t,s} - \frac{1}{\|\mathbb{S}\|}\sum_{t\in\mathbb{T}}\sum_{s\in\mathbb{S}}\sum_{a\in\mathbb{A}} \boxed{c^{+}_{a,t}u_{a,t,s} + c^{-}_{a,t}l_{a,t,s}}$$



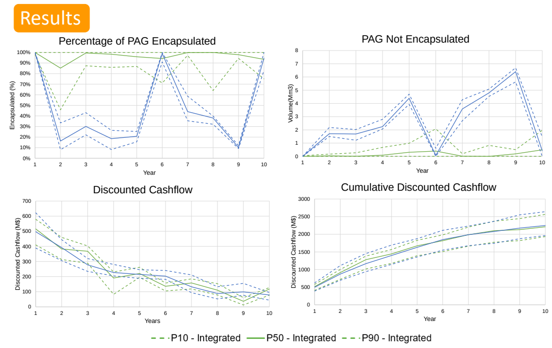
$$c^{-}_{NAG\ waste,t,s}\boxed{l_{NAG\ waste,t,s}}$$

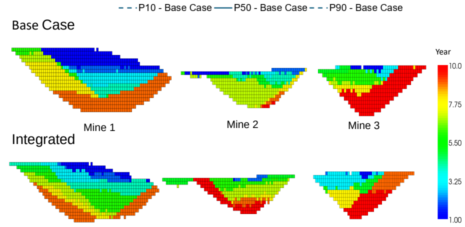
$$NAG\ Production_{t,s} - NAG\ Required_{t,s} + \boxed{l_{NAG\ waste,t,s}} \geq 0$$

Case Study at a Copper Mining Complex



Results





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4 Toward a robust control approach to the design of power hardware-in-the-loop interfaces

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Abstract: *The research project, conducted in collaboration with Hydro-Québec, aims to create a control interface that links real-time electrical grid simulations to renewable energy generation devices for testing purposes. This system will facilitate safe, efficient, and cost-effective testing of these technologies, enabling their integration into the grid and supporting the shift to cleaner energy sources. The design of the interface will leverage the tools of robust control theory to ensure stability and performance despite uncertainties in both the simulated grid and physical devices. After development, it will be validated using Hydro-Québec's infrastructure. This presentation aims to explain how, to date, an interface was designed for nominal operating conditions of the grid and device, and how such a design is insufficient for real-world application.*

Toward a Robust Control Approach to the Design of Power Hardware-in-the-loop Interfaces

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McGill GERAD

High-level Problem

- The power hardware-in-the-loop interfacing problem is to synthesize a simulation interface between a grid simulation and a power-generating device.
- The interface must be transparent, in that the grid-interface-device interconnection must mimic the reference grid-device interconnection, even in the presence of modelling uncertainty.

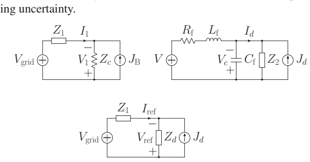
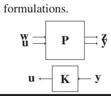


Figure 1: Linear circuit models of the grid simulation or rest of system (ROS, top left), power amplifier and device under test (DUT, top right), and reference system (REF, bottom).

- Upon successful synthesis of such an interface, a powerful testbed for renewable energy-generating devices becomes available to simulate at low cost the integration of such devices into the grid.

Methodology and Results

- Existing solutions to this problem include the ideal transformer method [1] and the transmission line method [2].
- Both of the above solutions are special cases of the generalized control framework [3].
- In this application, **P** is an appropriate combination of the DUT and ROS systems, as well as delays.
- The exogenous inputs **w** are V_{grid} and J_d.
- The control objectives **z**, which must be bounded or driven to zero in the steady state, are $V_1 - V_c$ and $I_1 - I_d$, weighted according to given performance specifications.
- The measurements are appropriately delayed versions of V_1, I_1, V_c, and I_d.
- The interface-generated actuation signals are V and J_{B}.
- The interface **K** is synthesized using either one the analytic equation-based or convex optimization-based formulations.



Methodology and Results (continued)

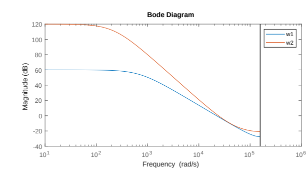


Figure 3: The magnitude response of the weights encoding the performance specifications.

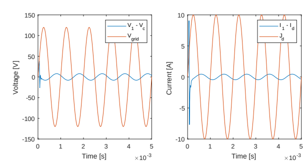


Figure 4: The time domain response of the grid-interface-device interconnection.

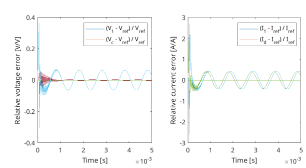


Figure 5: A comparison of the time domain responses of the grid-interface-device interconnection and the reference model. The synthesized interface is not quite transparent, which reveals a flaw in the control problem statement.

Low-level Problems and Project Direction

- The performance of the interface is guaranteed only for nominal operating conditions of the ROS and DUT
- Very poor, almost nonexistant robustness guarantees built into this particular interface
- Existing techniques to impose robustness onto the interface are only able to handle bounded modelling uncertainty [4].
- For the problem to be solved successfully, extreme operating conditions, presenting unbounded levels of modelling uncertainties, must be handled as well.
- As evidenced by Figure 5, the interface synthesized using the straightforward generalized control framework is not transparent.
- The objective of making ROS and DUT signals mimic each other seems to be an inadequate formulation of the problem.
- The generalized control problem generalizes the existing solutions in an unstructured way, but that seems to yield a hyper-sensitive focus on performance and no robustness.

Acknowledgments

Grateful thanks to my doctoral advisor, Professor J. Forbes, my industry partnership advisors, D. Rimorov and A. Kumar, my project teammate, A. Meagher, and my home research group, DECAR, for their helpful, insightful questions and comments.

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5 Optimising electric vehicle wireless charging systems using neural networks to enable free-position parking

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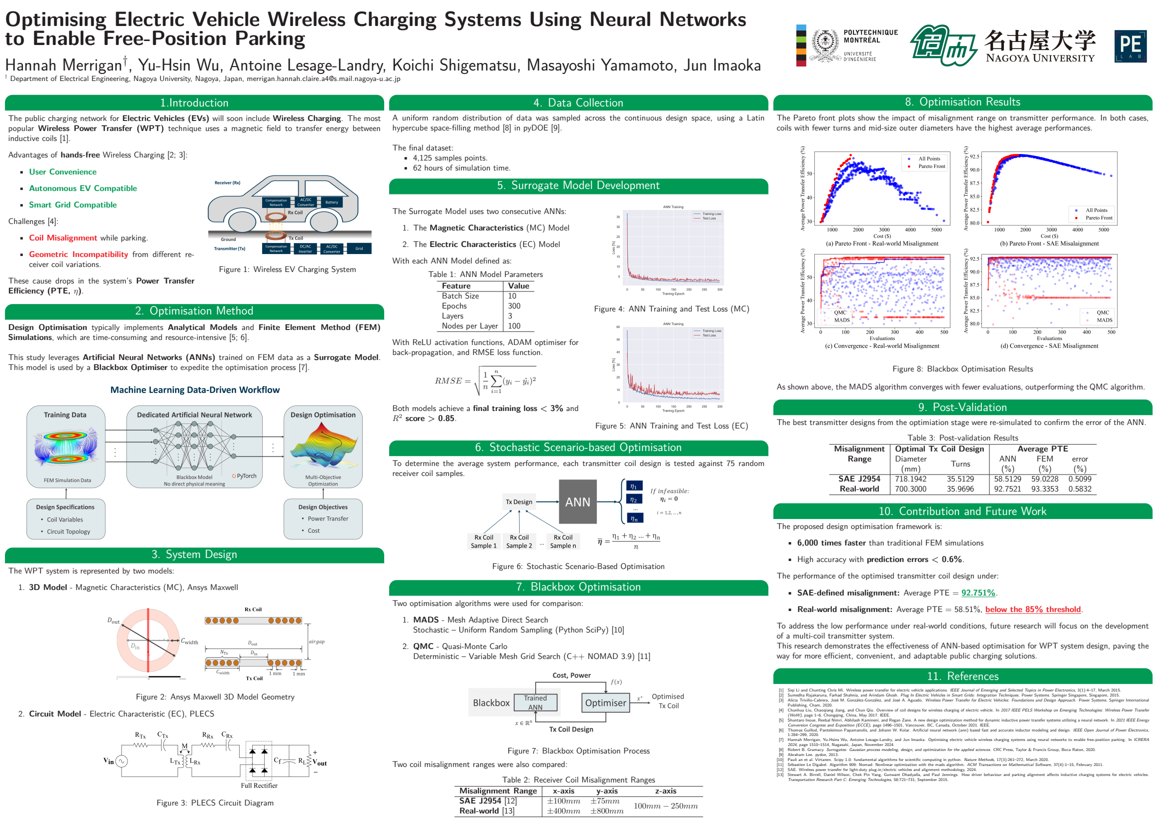
Abstract: *This study explores wireless power transfer (WPT) systems for public electric vehicle charging, focusing on optimising the transmitter design to enhance interoperability across various receiver coil geometries and alignment conditions. Due to the complex non-linear relationships inherent to WPT systems, traditional optimisation methods are computationally expensive. Therefore, this study proposes an approach using artificial neural networks (ANNs) trained on finite element method (FEM) data to develop a surrogate model of the WPT system. This model is integrated into a blackbox optimisation solver, enabling faster identification of improved transmitter designs. The proposed method achieves computational speeds 6,000 times faster than traditional FEM simulations, with post-validation on the final solutions verifying prediction errors below 0.6%. The results demonstrate a significant acceleration in the optimisation process, establishing this method as an effective framework for developing practical WPT systems for public charging applications.*



Optimising Electric Vehicle Wireless Charging Systems Using Neural Networks to Enable Free-Position Parking

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1. Introduction

The public charging network for **Electric Vehicles (EVs)** will soon include **Wireless Charging**. The most popular **Wireless Power Transfer (WPT)** technique uses a magnetic field to transfer energy between inductive coils [1].

Advantages of **hands-free** Wireless Charging [2; 3]:

- **User Convenience**
- **Autonomous EV Compatible**
- **Smart Grid Compatible**

Challenges [4]:

- **Coil Misalignment** while parking.
- **Geometric Incompatibility** from different receiver coil variations.

These cause drops in the system's **Power Transfer Efficiency (PTE, η)**.

Figure 1: Wireless EV Charging System

2. Optimisation Method

Design Optimisation typically implements **Analytical Models** and **Finite Element Method (FEM) Simulations**, which are time-consuming and resource-intensive [5; 6].

This study leverages **Artificial Neural Networks (ANNs)** trained on FEM data as a **Surrogate Model**. This model is used by a **Blackbox Optimiser** to expedite the optimisation process [7].

Machine Learning Data-Driven Workflow

3. System Design

The WPT system is represented by two models:

1. **3D Model** - Magnetic Characteristics (MC), Ansys Maxwell

Figure 2: Ansys Maxwell 3D Model Geometry

2. **Circuit Model** - Electric Characteristic (EC), PLECS

Figure 3: PLECS Circuit Diagram

4. Data Collection

A uniform random distribution of data was sampled across the continuous design space, using a Latin hypercube space-filling method [8] in pyDOE [9].

The final dataset:
- 4,125 samples points.
- 62 hours of simulation time.

5. Surrogate Model Development

The Surrogate Model uses two consecutive ANNs:

1. The **Magnetic Characteristics** (MC) Model
2. The **Electric Characteristics** (EC) Model

With each ANN Model defined as:

Table 1: ANN Model Parameters

Feature	Value
Batch Size	10
Epochs	300
Layers	3
Nodes per Layer	100

With ReLU activation functions, ADAM optimiser for back-propagation, and RMSE loss function.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

Both models achieve a **final training loss $< 3\%$** and **R^2 score > 0.85**.

Figure 4: ANN Training and Test Loss (MC)

Figure 5: ANN Training and Test Loss (EC)

6. Stochastic Scenario-based Optimisation

To determine the average system performance, each transmitter coil design is tested against 75 random receiver coil samples.

$$\bar{\eta} = \frac{\eta_1 + \eta_2 \ldots + \eta_n}{n}$$

Figure 6: Stochastic Scenario-Based Optimisation

7. Blackbox Optimisation

Two optimisation algorithms were used for comparison:

1. **MADS** - Mesh Adaptive Direct Search
Stochastic – Uniform Random Sampling (Python SciPy) [10]
2. **QMC** - Quasi-Monte Carlo
Deterministic – Variable Mesh Grid Search (C++ NOMAD 3.9) [11]

Figure 7: Blackbox Optimisation Process

Two coil misalignment ranges were also compared:

Table 2: Receiver Coil Misalignment Ranges

Misalignment Range	x-axis	y-axis	z-axis
SAE J2954 [12]	$\pm 100mm$	$\pm 75mm$	$100mm - 250mm$
Real-world [13]	$\pm 400mm$	$\pm 800mm$	

8. Optimisation Results

The Pareto front plots show the impact of misalignment range on transmitter performance. In both cases, coils with fewer turns and mid-size outer diameters have the highest average performances.

(a) Pareto Front - Real-world Misalignment
(b) Pareto Front - SAE Misalaignment
(c) Convergence - Real-world Misalignment
(d) Convergence - SAE Misalignment

Figure 8: Blackbox Optimisation Results

As shown above, the MADS algorithm converges with fewer evaluations, outperforming the QMC algorithm.

9. Post-Validation

The best transmitter designs from the optimiation stage were re-simulated to confirm the error of the ANN.

Table 3: Post-validation Results

Misalignment Range	Optimal Tx Coil Design		Average PTE		
	Diameter (mm)	Turns	ANN (%)	FEM (%)	error (%)
SAE J2954	718.1942	35.5129	58.5129	59.0228	0.5099
Real-world	700.3000	35.9696	92.7521	93.3353	0.5832

10. Contribution and Future Work

The proposed design optimisation framework is:

- **6,000 times faster** than traditional FEM simulations
- High accuracy with **prediction errors $< 0.6\%$**.

The performance of the optimised transmitter coil design under:

- **SAE-defined misalignment:** Average PTE = **92.751%**.
- **Real-world misalignment:** Average PTE = 58.51%, **below the 85% threshold**.

To address the low performance under real-world conditions, future research will focus on the development of a multi-coil transmitter system.
This research demonstrates the effectiveness of ANN-based optimisation for WPT system design, paving the way for more efficient, convenient, and adaptable public charging solutions.

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6 Impact of the car fleet evolution on electricity demand in Québec

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Abstract: *Under pressure to reduce greenhouse gas emissions, the global passenger car market is currently experiencing a shift from vehicles powered by internal combustion engines towards hybrid and fully electric models. Through an analysis of registered light-duty vehicles in Quebec, Canada, from 2011 to 2021, this study forecasts the evolving fleet's electricity demand under various electrification scenarios. The data indicates a yearly average fleet growth of 67,276 vehicles and an annual mass increase of 11 kg per vehicle from 2011 to 2021. Based on these trends, our projections estimate an electricity demand of 7.68 TWh in 2030, 17.84 TWh in 2035, and 29.03 TWh if the fleet continues evolving similarly. However, stabilizing the electric vehicle mass at the 2021 level reduces electricity demand by 17.6% in 2040 at a cost of a fleet that's 25.9% lighter.*

Impact of the car fleet evolution on electricity demand in Québec.

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Introduction

Canada ranks as the **tenth largest** greenhouse gases (GHG) emitter worldwide [1]. Among Canada's emissions, the **transport sector** alone contributes a **significant 30%** [2]; understanding the impact of decarbonizing the sector is therefore **crucial**.
In Quebec, the transport sector is responsible for **43.3% of GHG emissions** [3]. To address this issue, the **2030 Plan for a Green Economy** announces the goal to reach **2 million electric vehicles** (EVs) on the road by 2030, while phasing out the sales of new fossil-fuel powered cars by 2035 [4].
Our research aims to assess how the **evolution of fleet size and weight** will impact the **electricity demand** in cold climates and how it affects the GHG emissions from internal combustion engine vehicles (ICEVs) and battery electric vehicles (BEVs) in a low carbon electricity mix.

Methodology

Databases from the Société de l'Assurance Automobile du Québec (SAAQ).

- 9,749,916 records of registered light-duty vehicles (LDVs) with 227,368,858 recorded transactions and 1,130,324 entries of vehicles taken off the road from 2011 to 2021.
- Information such as the manufacturer, the model, the fuel type, the vehicle year and the car weight.
- Supplementary information like the category, the fuel consumption and the electricity consumption is gathered from the Fuel Consumption Guide (FCG) from Natural Resources Canada's database [5].

Projected evolution of the EV fleet: scenario definition. We consider three scenarios for the weight evolution of BEVs: the first, business as usual (BAU), in which historical trends in mass increase continues, the second, mass restriction 1 (MR1) where only electric vehicles get heavier by converting the weight from a ICEV to a BEV and a third, mass restriction 2 (MR2) where the average mass is fixed at the 2021 value. In all cases, the growth in the total number of LDV is maintained at the averaged growth from the 2011 to 2021 fleet.

How to project the electricity demand?

1. Compare the mass of an ICEV to its equivalent BEV.
2. Estimate the typical electricity consumption relative to the mass of the BEV.
3. Knowing the number of vehicles, the mileage and the temperature, we project the electricity consumption.

Life-cycle assessment (LCA). As detailed in [6], a vehicle's total CO_2-eq. life-cycle emissions $E_{\text{life,tot}}$ is calculated as

$$E_{\text{life,tot}} = E_{\text{prod,tot}} + E_{\text{util,tot}} + E_{\text{recyc,tot}}$$

where $E_{\text{prod,tot}}$, $E_{\text{util,tot}}$ and $E_{\text{recyc,tot}}$ represent the total production, utilization and recycling emissions, respectively.

Results - Fleet evolution and electricity consumption

Figure 1 presents the weight and number evolution of the LDV fleet from 2011 to 2021. The fleet increases by an average of **67,276 vehicles each year**, with **492,216 new vehicles** added and an average mean mass per vehicle **yearly increase of 11 kg**.

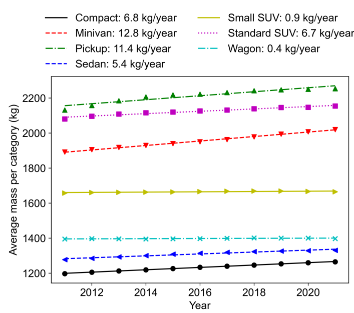

Figure 1: Mean mass per category for ICEVs relative to the year.

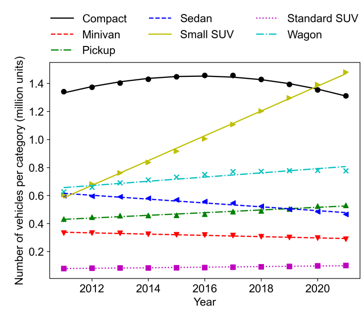

Figure 2: Number of ICEVs per category relative to the year.

Table 1 provides the electricity and power demand of the current automobile fleet as well as three milestones of the electrification. In 2040, the MR1 scenario lowers the power demand by 6.6%, with a fleet 9.6% lighter. For the MR2 scenario, the fleet would be **25.9% lighter** and would lead to a **17.6% decrease in electricity consumption**.

Table 1: Projected electricity demand for three scenarios of fleet evolution.

	Year	2021	2030	2035	2040	Unit
Fleet composition	Number of BEVs	72,199	2,000,000	4,366,356	6,733,712	
	Proportion of total fleet	1.3%	32.9%	68.2%	100%	
Total yearly electricity consumption	Business as usual	0.24	**7.68**	17.84	29.03	TWh
	Mass restriction 1	0.24	7.42	16.93	27.12	TWh
	Mass restriction 2	0.24	7.10	15.50	23.91	TWh
Power needed for a 24h day at -20°C	Business as usual	44	1392	**3232**	5261	MW
	Mass restriction 1	44	1344	3067	4915	MW
	Mass restriction 2	44	1287	2810	4332	MW

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Results - LCA

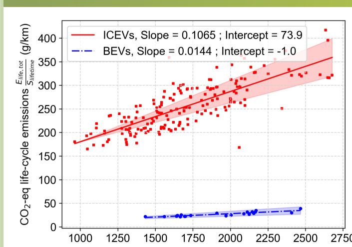

Figure 3: CO_2-eq. cradle-to-grave emissions of ICEVs and BEVs specific to Quebec's electricity mix, fleet composition and driving behavior.

Conclusion

This paper estimates the electricity needed to operate the future BEVs fleet and achieve a net-zero transport sector in the context of an evolving LDV fleet. We underscore the considerable challenges associated with the electrification of the transportation sector in Quebec, particularly in the province's seasonal variations. Evaluating whether it is more effective to increase electricity production to accommodate heavier BEVs or to limit the mass increase of the fleet to mitigate the electricity demand is crucial.
Furthermore, over the same average distance per category, we showed that **BEVs have significantly lower GHG emissions compared to ICEVs**, with a difference that increases for heavier vehicles.

7 Optimisation des manœuvres de contrôle sur les lignes de transport électrique

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Abstract: *Avec la demande croissante en énergie et l'intégration des sources d'énergie renouvelable, les réseaux électriques font face à d'importants défis opérationnels. Ces défis incluent les surcharges, les pertes de puissance et les instabilités du système, notamment lorsque les réseaux fonctionnent à proximité de leurs limites de capacité. Les dispositifs du réseau de transport jouent un rôle essentiel pour assurer l'exploitation sécurisée du réseau tout en facilitant l'intégration efficace des sources renouvelables afin de répondre à la demande croissante en électricité. Ce travail propose un modèle d'optimisation formulé sous forme de programme mixte en nombres entiers et à contraintes coniques du second ordre (MISOCP) pour la planification des actions de contrôle des dispositifs clés dans les systèmes de transport électrique, permettant ainsi d'améliorer l'efficacité opérationnelle du réseau et d'assurer une résolution efficace à l'aide de solveurs d'optimisation standards. Le modèle intègre (i) les changeurs de prise en charge (OLTC) pour gérer les niveaux de tension par des ajustements discrets des prises ; (ii) les compensateurs statiques synchrones (STATCOM) et les réactances shunt pour assurer la compensation de puissance réactive et la régulation de la tension ; et (iii) les condensateurs série à thyristors (TCSC) afin de contrôler l'impédance série et de réguler les flux de puissance. L'objectif du modèle est de minimiser les pertes de puissance active dans les lignes de transport en utilisant un nombre limité d'actions de contrôle, comme recommandé par l'opérateur, sur un horizon temporel donné, tout en garantissant le respect des contraintes opérationnelles et physiques à tout moment. Pour modéliser efficacement les contraintes imposées par les caractéristiques opérationnelles des dispositifs, des techniques de linéarisation et de relaxation sont appliquées. Plus précisément, une relaxation conique du second ordre (SOCR) est employée pour modéliser les flux de puissance au sein du problème d'optimisation tout en garantissant une résolution computationnelle. Les contraintes associées aux OLTC sont discrétisées à l'aide d'une expansion binaire avant d'être linéarisées. Les STATCOM sont modélisés à l'aide de contraintes linéaires basées sur leurs valeurs maximales et minimales de puissance réactive afin de représenter leur comportement d'injection et d'absorption. Une technique d'expansion binaire est également utilisée pour modéliser les réactances shunt, permettant l'agrégation de plusieurs valeurs discrètes de puissance réactive. De plus, une technique de reformulation-linéarisation (RLT) est appliquée afin de modéliser la contribution des TCSC de manière convexe. Afin d'assurer une représentation précise du problème, un modèle d'optimisation multi-période est employé. Cette approche prend en compte la nature séquentielle des actions de contrôle, où les décisions prises à un instant donné influencent celles adoptées aux étapes suivantes. Le modèle est testé sur les réseaux IEEE 9-bus et RTS 96 et comparé avec des modèles existants issus de la littérature. Les profils de tension et les pertes de puissance active sont évalués afin d'en mesurer la performance. Ces tests valident l'efficacité du modèle pour maintenir les tensions dans des limites acceptables tout en minimisant les pertes de puissance, soulignant ainsi son potentiel pour une application à des réseaux électriques de plus grande échelle.*

Optimisation des manœuvres de contrôle sur les lignes de transport électrique

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POLYTECHNIQUE MONTRÉAL · GERAD · Hydro Québec Institut de recherche · Mila

1. Mise en Context

Avec la demande croissante en énergie et l'intégration des sources d'énergie renouvelable, les réseaux électriques font face à d'importants défis opérationnels. Ces défis incluent les surcharges d'équipement et les pertes de puissance, notamment lorsque les réseaux sont opérés près de leurs limites de capacité.

2. Méthode et Formulation

Ce travail propose un modèle formulé sous forme de programme mixte en nombres entiers et sous contraintes coniques du second ordre MISOCP pour la planification des manœuvres de contrôle des dispositifs clés dans les systèmes de transport électrique.

Objective: $\min \sum_{t=1}^{24} \sum_{i,j \in \mathcal{L}} P^t_{i,j,\text{Loss}}$

Minimisation de la perte de puissance:

$P^t_{i,j,Loss} = p^t_{i,j} + p^t_{j,i} \quad \forall i,j \in \mathcal{L}, t \in \mathcal{T}$

+ Écoulement de puissance avec SOCR

Changeurs de prise en charge OLTC: [1]

$\sum_{n \in N^T_{tap}} \alpha^t_{tap,n} = 1 \qquad \forall tap = (d,i,OLTC) \in \mathcal{D}, \forall t \in \mathcal{T}$

$(v_{tap,max})^2 \le \tilde{U}^t_{tap} \le (v_{tap,max})^2 \qquad \forall tap = (d,i,OLTC) \in \mathcal{D}, \forall t \in \mathcal{T}$

$real(W^t_{i,i}) = \sum_{n \in N^T_{tap}} m^t_n \qquad \forall (i,j) \in \mathcal{L}, t \in \mathcal{T}$

$imag(W^t_{i,i}) = 0 \qquad \forall (i,j) \in \mathcal{L}, t \in \mathcal{T}$

$\Delta\alpha_{tap} = (\varphi_{tap})^2 \qquad \forall tap = (d,i,OLTC) \in \mathcal{D}$

$0 \le m^t_n \le M\, \alpha^t_{tap,n} \qquad \forall tap = (d,i,OLTC) \in \mathcal{D}, n \in N^T_{tap}, \forall t \in \mathcal{T}$

$m^t_n \le \tilde{U}^t_{tap}\, \Delta\alpha_{tap,n} + M\left(1 - \alpha^t_{tap,n}\right) \qquad \forall tap = (d,i,OLTC) \in \mathcal{D}, n \in N^T_{tap}, \forall t \in \mathcal{T}$

$m^t_n \ge \tilde{U}^t_{tap}\, \Delta\alpha_{tap,n} - M\left(1 - \alpha^t_{tap,n}\right) \qquad \forall tap = (d,i,OLTC) \in \mathcal{D}, n \in N^T_{tap}, \forall t \in \mathcal{T}$

Méthode *Big M* et expansion binaire pour linéariser

$$U^t_{tap} = \tilde{U}^t_{tap}(\varphi^t_{tap})^2$$

Compensateurs statiques synchrones STATCOM: [2][3]

$|q^t_{Stat}| \le q^{max}_{Stat} s^t_{Stat} + M(1 - s^t_{Stat}) \qquad \forall Stat = (d,i,Statcom) \in \mathcal{D}, \ t \in \mathcal{T}$

$|v^t_{Stat}| \le v^{max}_{Stat} s^t_{Stat} + M(1 - s^t_{Stat}) \qquad \forall Stat = (d,i,Statcom) \in \mathcal{D}, \ t \in \mathcal{T}$

Injection ou absorption de puissance réactive et tension si active

Réactanes Shunt :

$\sum_{n \in N^T_{shunt}} \alpha^t_{shunt,n} \le n$

$q^t_{shunt} \le \sum_{n \in N^T_{shunt}} \left(\alpha^t_{shunt,n} * q_{shunt,n}\right) + (1 - s^t_{shunt})\, M \qquad \forall shunt = (d,i,shunt) \in \mathcal{D}, t \in \mathcal{T}$

$q^t_{shunt} \ge \sum_{n \in N^T_{shunt}} \left(\alpha^t_{shunt,n} * q_{shunt,n}\right) + (1 - s^t_{shunt})\, M \qquad \forall shunt = (d,i,shunt) \in \mathcal{D}, t \in \mathcal{T}$

Injection de puissance réactive + possibilité d'agrégation

Condensateurs série à thyristors TCSC: [4][5] (Assumption : $X_{ij} > 0$)

$-0.8X_{ij} < X_{TCSC} < 0.2X_{ij} \qquad \forall (i,j) \in \mathcal{L}, TCSC = (d,TCSC,l) \in \mathcal{D}, \ t \in \mathcal{T}$

$-\frac{1}{X_{ij} + X_{TCSC,max}} - M(1 - s^t_{TCSC}) \le \Delta B_{TCSC} \qquad \forall (i,j) \in \mathcal{L}, TCSC = (d,TCSC,l) \in \mathcal{D}, \ t \in \mathcal{T}$

$\Delta B_{TCSC} \le -\frac{1}{X_{ij} + X_{TCSC,min}} + M(1 - s^t_{TCSC}) \qquad \forall (i,j) \in \mathcal{L}, TCSC = (d,TCSC,l) \in \mathcal{D}, \ t \in \mathcal{T}$

$-Ms^t_{TCSC} \le \Delta B_{TCSC} \le Ms^t_{TCSC} \qquad \forall TCSC = (d,TCSC,l) \in \mathcal{D}, \ t \in \mathcal{T}$

$p^t_{i,j} + jq^t_{i,j} = \left(W^t_{i,i} - W^t_{i,j}\right)\left(Y_{ij} + \Delta Y^t_{ij}\right)^* \qquad \forall (i,j) \in \mathcal{L}, t \in \mathcal{T}$

$\Delta Y^t_{ij} = j\Delta B^t_{ij} \qquad \forall (i,j) \in \mathcal{L}, t \in \mathcal{T}$

+ Relaxation avec la technique *Formulation-Linearization*

Contrôle:

Maximum m action de contrôle chaque à t

$\sum_{dev,tap \in \mathcal{D}} |s^t_{dev} - s^{t-1}_{dev}| + o^t_{tap} \le m \qquad t \in \{2,3,\dots,\mathcal{T}\}$

Changement maximal permis par action du OLTC

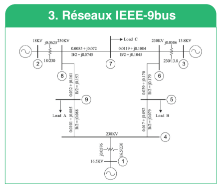
$|u^t_{tap} - u^{t-1}_{tap}| \le o^t_{tap}\Delta Limit_{tap} \qquad \forall tap = (d,i,OLTC) \in \mathcal{D}, \forall t \in \{2,3,\dots,\mathcal{T}\}$

Lien entre la représentation binaire et entière de la position du OLTC à t

$u^t_{tap} = \sum_{n \in N^T_{tap}} n\, \alpha^t_{tap,n} \qquad \forall tap = (d,i,OLTC) \in \mathcal{D}, \forall t \in \mathcal{T}$

$$s^t_{dev} \in \{0,1\}, \ o^t_{tap} \in \{0,1\}, \ u^t_{tap} \in \{1,2,\dots,N^T_{tap}\}, \ \alpha^t_{tap,n} \in \{0,1\}$$

3. Réseaux IEEE-9bus



4. Profile de voltage sans équipement

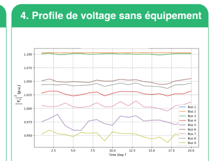


Figure 1. Baseline Voltage Profile Over Time

5. Résultats

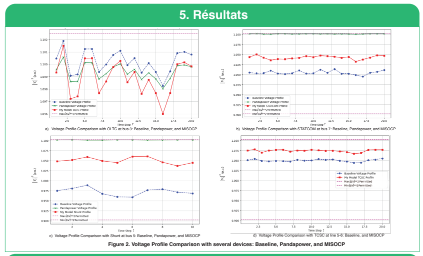


Figure 2. Voltage Profile Comparison with several devices: Baseline, Pandapower, and MISOCP

6. Validation du modèle

- Testé sur le réseau IEEE 9-bus et comparé aux modèles de la littérature.
- Évaluation des profils de tension et des pertes de puissance active.
- Résultats confirmant l'efficacité du modèle pour maintenir les tensions dans les limites acceptables et minimiser les pertes.

7. Futurs travaux

- Application au réseau RTS96 pour une évaluation sur un système plus complexe.
- Inclusion des ressources énergétiques distribuées (DER), source d'incertitude.
- Exploration d'approches stochastiques pour mieux gérer la variabilité et renforcer la robustesse du modèle.

8. References

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8 Participation des clients à la gestion optimisée des charges électriques : intégration d'un logiciel homme-machine pour le contrôle intelligent de l'électricité

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Abstract: *Le projet vise à développer un logiciel interactif pour optimiser la gestion des charges électriques résidentielles. Objectifs : a) Réduire le gaspillage énergétique (jusqu'à 30 %) b) Optimiser la consommation et équilibrer l'offre et la demande c) Encourager la participation active des utilisateurs grâce à une interface intuitive d) Promouvoir l'efficacité énergétique et réduire l'empreinte carbone. Le projet contribue à une gestion énergétique durable et à la réduction des coûts pour les utilisateurs.*