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open ENTRANCE
European Commission

Research Plan Proposal: Optimal Power Grid Design for a Low Carbon Emission Future

“to efficiently deliver sustainable, economic and secure electricity supplies”

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European context

Paris agreement: To keep the increase in global average temperature below 2°C above pre-industrial levels (preferred target 1.5°C)

2020

20% reduction in greenhouse gas emissions compared to 1990

20% renewable share on gross final energy consumption

20% reduction in primary energy consumption

10% electricity interconnection

2030

40% reduction in greenhouse gas emissions compared to 1990

32% renewable share on gross final energy consumption

32.5% reduction in primary energy consumption

15% electricity interconnection

2050

Low carbon emissions future

Climate neutral economy

Framework 2021-2030

- Energy and economic efficiency
- New energy rulebook (National Energy and Climate Plan)
- More rights for consumers
- Increased security of the system supported by a smarter and more efficient electricity system

More details can be found in: https://ec.europa.eu/clima/policies/strategies_en

Optimal Power Grid Design (OPGD)

To make an OPGD, the following is taken in consideration:

Context	A Low Carbon Emission Future
Scenario	Quantitative European scenarios[1]
Optimization problem	Transmission Expansion Planning (TEP)
Investments	new lines, PST, FACTS, switchable elements to provide operational flexibility
Operational difficulties	AC power flow, ESS operation, and topology optimization
Case study	Large-scale european case

Main dimensions in Transmission Expansion Planning (TEP) related to network flexibility:

- Network representation
- Temporal representation
- Decision dimension

[1] D3.1 Quantitative Scenarios for Low Carbon Futures of the pan-European Energy System
Source: https://openentrance.eu/2020/06/26/quantitative-scenarios/

European context
Optimal Power Grid Design (OPGD)
Literature review
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Literature review: TEP (see slide: Reference I)

	Papers	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]
Temporal Representation	Static or Dynamic?	Static	Dynamic	Static	Static	Static	Static	Static	Static	Dynamic	Static	Static
	Load levels	75 snapshots	1 block	1 block	4 days	5 blocks	1 block	8760 h	1350 h	4 blocks per year	1500 h	25 h
Network Representation	Case study	Europe	IEEE118	RTS-24	RTS	Chile	RTS-24	Europe	RTS-24	1168-bus	IEEE300	RTS
	Nodes	1000	118	24	72	27	24	2088	24	1168	300	72
	ESS	-	-	-	Yes	Yes	-	-	-	-	-	-
	HVDC	Yes	-	-	-	-	-	Yes	-	-	-	-
	PST	-	-	-	-	-	-	-	-	-	-	Yes
	FACTS	-	-	-	-	-	-	-	-	-	-	Yes
	Network modification	-	-	Lines	Lines	-	Splitting of lines	-	-	Lines	-	-
	DC OPF	Cycles	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-
	AC OPF	-	Linear Branch flow	-	-	-	-	-	-	-	-	Quadratic Convex Polar
Decision dimension	Search space	-	-	-	-	-	-	Candidates procedure	-	Candidates predefined	-	-
	Problem type	MILP	MILP	MILP	Trilevel & MILP	MILP	MILP	LP & MILP	MILP	MILP	Benders & MILP	NLP & MILP

Research gaps:

- A better network representation
- PST, FACTS, and switchable elements: Power flow control & topology optimization
- A suitable search space reduction including PST, FACTS, and switches
- A temporal representation with chronological constraints

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Objective

To deal with the needs of a low carbon emission future, network expansion and operation planning should be more accurate and flexible, while also being represented in a more compact way.

Sub-objectives :

How can we achieve these improvements?

- Exploring the formulation of an AC power flow model considering cycle constraints in TEP
- Exploring the deployment of switchable elements for topology optimization and PST & FACTS for power flow control to increase network flexibility
- Identifying policy implications for the development and operation of regional systems through the application of the enhanced model to quantitative European scenarios[1] (optional)

- ❑ **Network operation representation using AC power flow with cycle constraints**
- ❑ **Topology optimization and power flow control within expansion planning**
- ❑ **Search space reduction considering PST, FACTS, and switchable elements**
- ❑ **Representative periods with chronological interdependency**
- ❑ **Definition of policy implications for network development**

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Problem definition

Transmission Expansion Planning (TEP)

AC power flow with cycles constraints

- How the cycle approach can be adapted from its application in DC load flow to AC load flow? *(ref. [1])*
- What impact on costs does TEP when considers AC instead of DC power flow?
- What impact in time happens when 'circular flows' is used instead of the traditional formulation?

Topology Optimization
Power Flow Control
Search Space Reduction

- Is it possible that the network flexibility is increased even more considering the topology optimization in the TEP? *(ref. [2])*
- What approach between marginal and incremental benefits offers a suitable calculation of equipment benefits?

Chronological interdependency

- Is it possible to get snapshots selection with chronological interdependency? *(e.g., ref. [3])*
- What is the impact of including chronological constraints in the TEP problem in terms of increased efficiency?

Expected outputs

Nº	Contribution
1	Network operation representation using AC power flow with cycle constraints
2	TEP considering topology optimization & TEP considering power flow control
3	Search space reduction considering PST, FACTS, and switchable elements
4	Representative periods with chronological interdependency – representation of intertemporal constraints

[1] Neumann, Fabian, and Tom Brown. "Transmission Expansion Planning Using Cycle Flows." Proceedings of the Eleventh ACM International Conference on Future Energy Systems. 2020.
[2] Tejada, Diego, et al. "Transmission network expansion planning considering repowering and reconfiguration." International Journal of Electrical Power & Energy Systems 69 (2015): 213-221.
[3] Baumgärtner, Nils, et al. "RiSES3: Rigorous Synthesis of Energy Supply and Storage Systems via time-series relaxation and aggregation." Computers & Chemical Engineering 127 (2019): 127-139.

Leveraging the Power Grid with openTEPES

Model	Optimization problem	Transmission Expansion Planning
	Model type	MILP
	Static	1 year considering representative periods with chronological interdependency
	Network investment	Lines & Transformers + Switchable elements + FACTS + PST
	System operation	Unit commtment + DC power flow/Linear AC power flow + topology optimization
	Decision dimension	Search space considering including PST, FACTS and switchable elements
Case Study	Nodes	> 100, Busbars at voltage level > 220 kV, (RTS72, IEEE118, openENTRANCE)
Scenarios	Quantitative Scenarios[1]	Directed transition
		Societal commitment
		Techno-friendly
		Gradual development

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PhD schedule

		2019				2020				2021				2022				2023				2024			
Item	Checkpoint	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Literature review			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨						
2	Building case studies and reference case study considering Quantitative Scenarios					🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨						
4	Inclusion of cycle constraints to the linear AC load flow formulation						🟩	🟩	🟩	🟩															
4.1	Mathematical formulation, implementation and testing						🟩	🟩																	
4.2	Application to the case study and analysis of results							🟩	🟩																
P1	Paper 1, about AC power flow with cycle constraints								🟩	🟩	🟩														
P2	Paper 2, An Integrated Expansion Planning Model Considering an AC-OPF with Cycle Constraints and Detailed UC Constraints								🟩	🟩	🟩	🟨													
P3	Paper 3, Value and Impact of Using Local Flexibility into the Transmission Expansion Planning								🟩	🟩	🟩	🟨													
5	Inclusion of PST, FACTS and switchable elements										🟩	🟨	🟨	🟨											
5.1	Methodology definition, implementation and testing										🟩	🟨	🟨												
5.2	Application to the case study and analysis of results											🟨	🟨	🟨	🟨										
P4	Paper 4, TEP + topology optimization											🟨	🟨												
P5	Paper 5, Search space reduction considering PST, FACTS, and switchable elements													🟨	🟨										
6	Representative periods with chronological interdependency														▨	▨	▨	▨							
6.1	Methodology definition, implementation and testing														▨	▨									
6.2	Application to the case study and analysis of results															▨	▨								
P6	Paper 6, Representative periods with chronological interdependency																▨	▨							
7	PhD thesis documentation																		▨						

🟩 Accomplished task
🟨 Remaining task
▨ Identified task

Checkpoint: Second year work

- Literature review
  - → TEP & AC-OPF models **(Item 4: P2)**
  - → Topology optimization: optimal transmission switching & bus splitting **(Item 5: P4)**
- Updating the RTS24 case study according to [4] **(Item 4.2: P2, P3)** **(Item 5.2: P4)**
- Tools
  - → Getting representative periods, each one comprising 24 hours **(Item 4.1: P2)**
  - → Getting line benefits by a modified version of the PINT & TOOT approach **(Item 5.1: P4)**
  - → Getting switching stages, linked with temporal reduction **(Item 5.1: P4)**
- Modelling
  - → Transmission line switching in openTEPES **(Item 5.1: P4)**
  - → AC-OPF models: DistFlow & Bus Injection. Power Mismatch Validation & Bounds Tightening **(Item 4.1: P2)**
- Analysis
  - → Comparison of MISOCP and MILP version of the AC-OPF in openTEPES **(Item 4.1: P2)**
- Papers (to be sent to PSCC)
  - → P2: An Integrated Expansion Planning Model Considering an AC-OPF with Cycle Constraints and Detailed UC Constraints
  - → P3: Value and Impact of Using Local Flexibility into the Transmission Expansion Planning

[4] Barrows, Clayton, et al. "The IEEE reliability test system: A proposed 2019 update." IEEE Transactions on Power Systems 35.1 (2019): 119-127.

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Remaining tasks

- Literature review
  - → Power flow control: PST & FACTS **(Item 5: P5)**
  - → Search space reduction techniques **(Item 5: P5)**
  - → Temporal reduction techniques with chronology interdependency **(Item 6: P6)**
- Data for reference case study considering European Quantitative scenarios[1] : **(Item 5.2: P5) (Item 6.2: P6)**
- Modelling
  - → Topology optimization:
    - → Modelling the bus splitting **(Item 5.1: P4)**
    - → Design a strategy for topology optimization, it should harmonize the switching stages and line switching options with the bus splitting **(Item 5.1: P4)**
  - → Advanced power flow control
    - → Modelling PST and FATCS, grouped with the switchable elements in a joint strategy **(Item 5.1: P5)**
  - → Search space reduction considering PST, FACTS, and switchable elements **(Item 5.1: P5)**
  - → Representative periods with chronological interdependency **(Item 6.1: P5)**

<u>**Legend:**</u>
- FACTS : Flexible Alternating Current Transmission System
- PST : Phase Shifting Transformers

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“The new becomes old, and the old becomes new…a life cycle”

спасибо 谢谢

GRACIAS

THANK YOU

ありがとうございました MERCI

DANKE धन्यवाद

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