Transmission Expansion Planning using a Highly Accurate AC Optimal Power Flow Approximation

Otto Heide, Karlo Šepetanc, Hrvoje Pandžić

Faculty of Electrical Engineering and Computing,

Department of Energy and Power Systems

Presentation outline

1. Motivation
2. Formulation of optimization problem
3. Case study
4. Results
5. Conclusion

Motivation

- Continuous increase in demand levels

  → More lines will become congested
- Increased penetration of renewable energy sources (RES)

  → Uncertainty arises and flexibility of power system is disrupted
- Nonlinear and non-convex optimization of power transmission system expansion planning (TEP)

  → Relaxation and approximation optimization models

  → High accuracy and good computational tractability is required

Formulation of MIQCQP AC-TEP Framework

Objective

→ Minimize the total power system operation and expansion costs

$$Min \sum_{t,k} (\ddot{\boldsymbol{c}}_k \cdot (P^{\mathrm{g}}_{t,k})^2 + \dot{\boldsymbol{c}}_k \cdot P^{\mathrm{g}}_{t,k} + \boldsymbol{c}_k + \sum_{e \in E^+} z_e \cdot cost_e)$$

Constraints

- Active and reactive power balance constraints
- RES active power production limits
- Voltage and line flow limit constraints
- Prospective lines for the expansion process
- Presolve process for Convex Polar Second-Order Taylor Approximation AC-TEP model

Convex Polar Second-Order Taylor Approximation AC-TEP model

- Quadratically constrained voltage magnitudes and angles
- High accuracy due to the elimination of constraint relaxation errors determined by the presolve process
- Presolve process decides whether to use the quadratic inequality or the linear equality formulation of power flow constraints

Presolve process

$$\check{V}_{t,e} \geqslant \frac{\boldsymbol{g}_e + \boldsymbol{g}_e^{\mathbf{fr}}}{\boldsymbol{\tau}_e^2} \cdot (V_{t,i}^{\Delta})^2 - \frac{2 \cdot \boldsymbol{g}_e}{\boldsymbol{\tau}_e} \cdot \cos(\boldsymbol{\theta}_{t,i}^{\mathbf{op}} - \boldsymbol{\theta}_{t,j}^{\mathbf{op}} - \boldsymbol{\sigma}_e) \cdot V_{t,i}^{\Delta} \cdot V_{t,j}^{\Delta}$$
$$+ (\boldsymbol{g}_e + \boldsymbol{g}_e^{\mathbf{to}}) \cdot (V_{t,j}^{\Delta})^2, \quad \forall t, (e,i,j) \in (E \cup E^+) : \boldsymbol{g}_e > 0 \wedge \Lambda_{t,e}$$

$$\check{V}_{t,e} = 0, \quad \forall t, (e,i,j) \in (E \cup E^+) : \boldsymbol{g}_e \leqslant 0 \vee \neg \Lambda_{t,e}$$

$$\widehat{cos}_{t,i,j} \leqslant 1 - \frac{(\theta_{t,i}^{\Delta} - \theta_{t,j}^{\Delta})^2}{2}, \quad \forall t, (i,j) \in N^{\mathrm{P}} : \Gamma_{t,i,j}$$

$$\widehat{cos}_{t,i,j} = 1, \quad \forall t, (i,j) \in N^{\mathrm{P}} : \neg \Gamma_{t,i,j}$$

Case Study

- Two TEP test cases: IEEE 24-bus and IEEE 73-bus (RTS96) systems
- Modification of presented networks were made to capture different time intervals and to incur congestion
- Wind power generation unit integration
- Identifying of prospective transmission expansion line candidates
- Solving of TEP problem

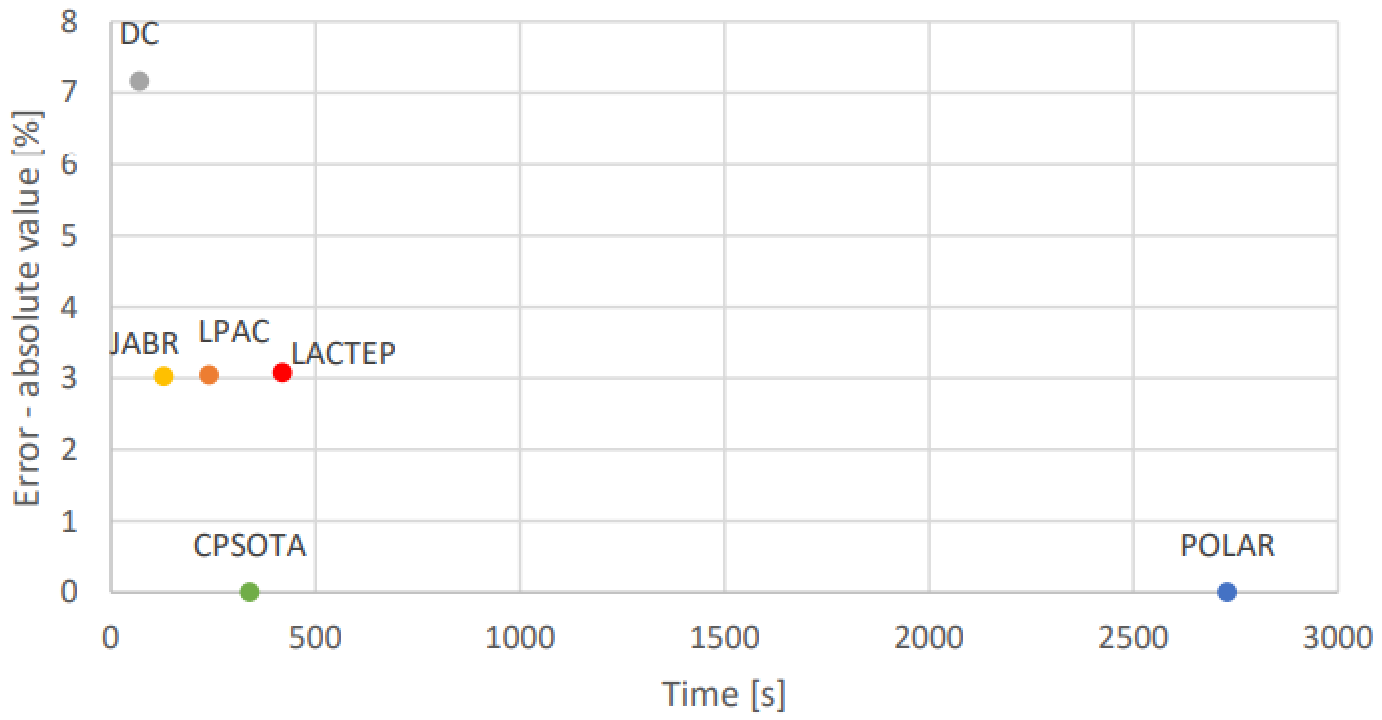
Results

→ IEEE 24 bus system

Model	Time [s]	Expansion plan	Total cost	Error [%]
POLAR (MINLP)	2730	L7, L13, L23	4.0359299 E+09	0
LPAC (MIQCQP)	240	L7, L12, L13 L21, L22, L23, L28	3.9130797 E+09	-3.044
DC (MILP)	70	L12, L22, L23, L28	3.7468042 E+09	-7.164
JABR's (MISOCP)	130	L7, L12, L13 L21, L22, L23, L28	3.9138228 E+09	-3.026
LACTEP (MILP)	370	L7, L11, L12, L13 L21, L22, L23, L28	3.9116847 E+09	-3.078
CPSOTA (MIQCQP)	340	L7, L13, L23	4.0361073 E+09	0.004

Results

→ IEEE 24 bus system



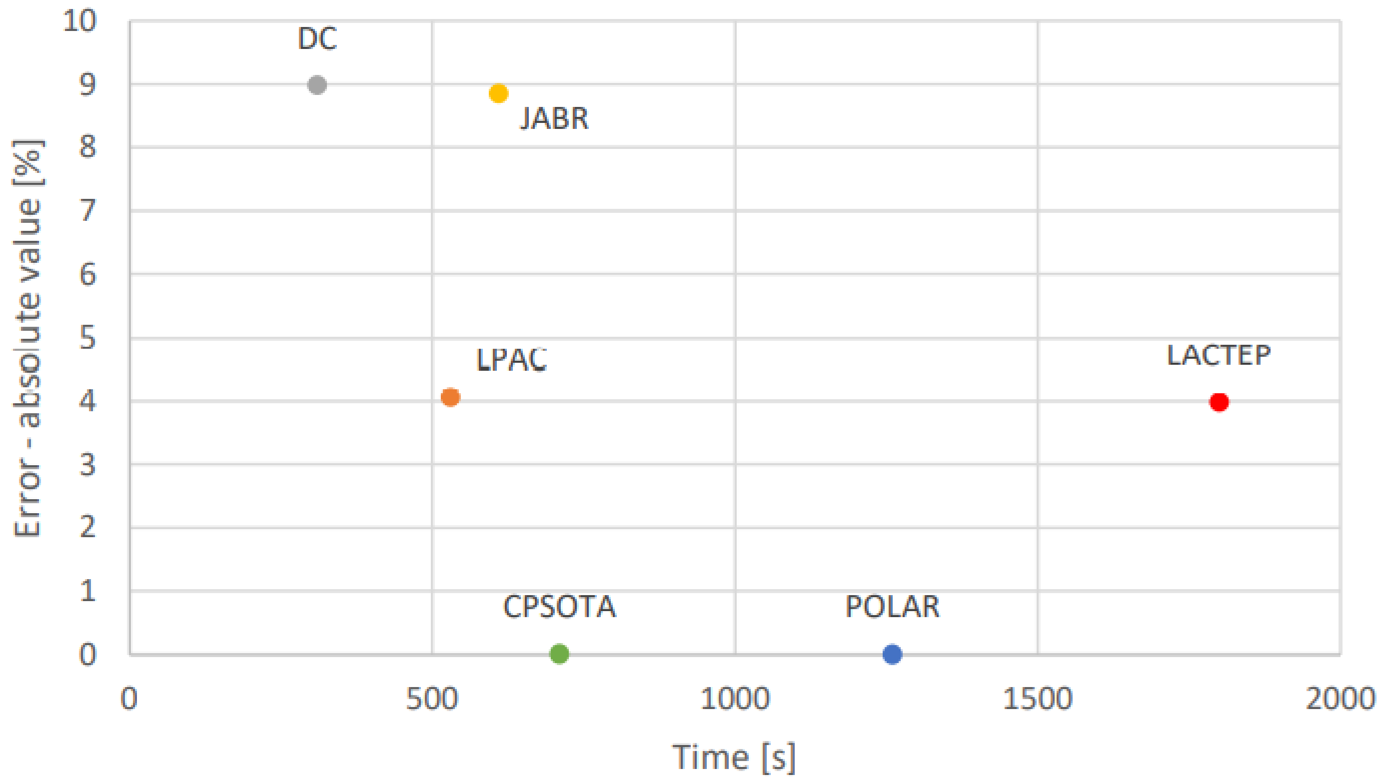
Results

→ IEEE 73 bus system

Model	Time [s]	Expansion plan	Total cost	gap [%]
POLAR (MINLP)	1260	L30, L90	1.390911 E+10	0
LPAC (MIQCQP)	530	L25, L53, L91, L102	1.334429 E+10	-4.061
DC (MILP)	310	L53	1.265998 E+10	-8.981
JABR's (MISOCP)	610	L30, L53 L69, L90, L91	1.267801 E+10	-8.851
LACTEP (MILP)	1800	L25, L53 L69, L90, L91	1.335497 E+10	-3.984
CPSOTA (MIQCQP)	710	L30, L90	1.390794 E+10	-0.008

Results

→ IEEE 73 bus system



Conclusion

- Power flow formulation vary with accuracy and computational tractability
- CPSOTA’s TEP performance is demonstrated on two modified test cases
- Construction of new transmission power lines shifts the cost from operation to investment
- TEP process eventually provides saving in total costs

This research work has received funding from the European Union’s Horizon 2020 research and innovation program under grant agreement No864298 (project ATTEST).

Thank you!

otto.heide@fer.hr,
karlo.sepetanc@fer.hr,
hrvoje.pandzic@fer.hr