Scalable Optimization Techniques with Line-Flow Penalty for Improving Transmission Constraints Problems

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MOTIVATION

- Power system scheduling is becoming more challenging in recent times. This is due to the increase in Distributed Energy Resources (DER) and technologies like Demand Response (DR) and virtual trading on the power grid.
- The integration of these advancements without adequate investments could lead to an increase in the volume of transmission constraints on the power grid.
- Day Ahead Unit Commitment and Economic Dispatch problems with a high volume of virtual trading and transmission constraints are usually very difficult to solve and require a lot of iterations.
- A new Lagrangian Relaxation (LR) formulation is designed to alleviate the transmission constraint problems by identifying and penalizing transmission lines with binding transmission flow limits.
- The appropriate penalty is derived using the system network data.

Proposed LR HEURISTIC

Lagrange Formulation

$$min \quad F_i^t(P_i^t) = a + bP_i^t + c(P_i^t)^2$$
$$st \quad P_{load}^t - \sum_{i=1}^{N} P_i^t U_i^t = 0$$
$$U_i^t P_i^{min} \le P_i^t \le U_i^t P_i^{max}$$
$$F_T = \sum_{i=1}^{N}(a + bP_i + cP_i^2)$$

Primal

$$L(P,\lambda) = \sum_{i=1}^{T}\Big(\sum_{i=1}^{N}\big(a + bP_i + cP_i^2\big)U_i^t + \sum_{t=1}^{T}\lambda^t\big(P_{load}^t - \sum_{i=1}^{N}P_i^t U_i^t\big)\Big)$$
$$L(P,\lambda) = \sum_{t=1}^{T}\sum_{i=1}^{N}\big(a + bP_i + cP_i^2\big)U_i^t + \sum_{t=1}^{T}\lambda^t\big(P_{load}^t - \sum_{i=1}^{N}P_i^t U_i^t\big)$$

Dual

$$D(\lambda) = \sum_{i=1}^{N}\big(a + bP_i + cP_i^2\big)U_i^t + \lambda^t\big(P_{load}^t - \sum_{i=1}^{N}P_i^t U_i^t\big)$$
$$\frac{dD(\lambda)}{d\lambda} = grad = P_{load}^t - \sum_{i=1}^{N}P_i^t$$
$$\lambda^t = \lambda^t + \Big(\frac{dD(\lambda)}{d\lambda}\Big)\alpha$$

Heuristic Using Linearized Line-Losses

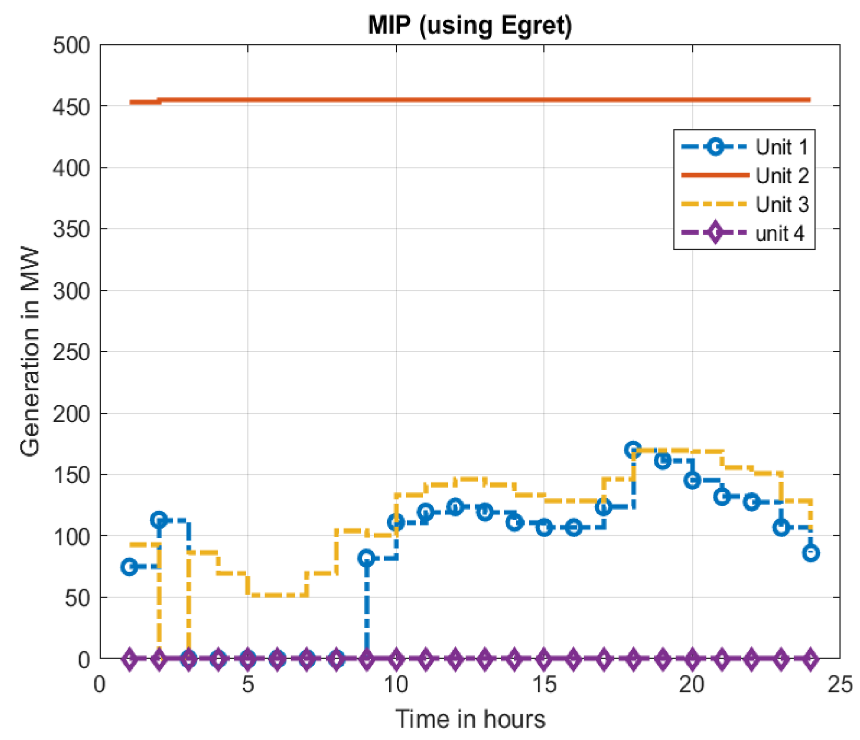
$$L(P,\lambda) = \sum_{t=1}^{T}\sum_{i=1}^{N}\big(a + bP_i + cP_i^2\big)U_i^t + \sum_{t=1}^{T}\lambda^t\Big(P_{load}^t + \sum_{j=1}^{L}\big(L_{flow}^t(P_{1,2\ldots ng})\big)^2 R_j - \sum_{i=1}^{N}P_i^t U_i^t\Big)$$

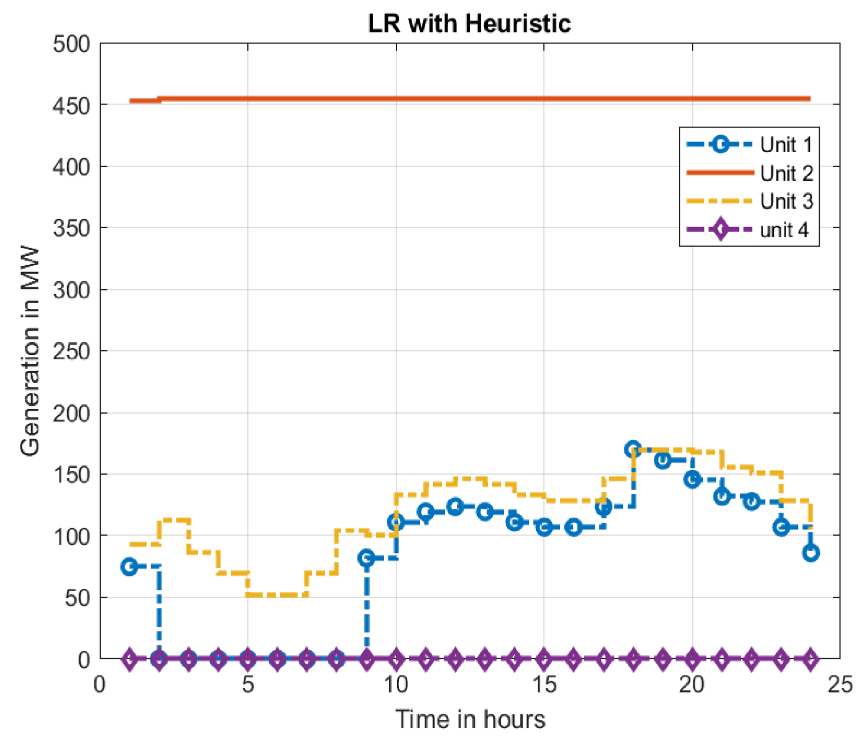
$$L_{flow}^t(P_{1,2\ldots ng}) = \sum_{i=1}^{N} GSF_{k-i} \times [P_i - D_i]$$

$$\sum_{j=1}^{L}\big(L_{flow}^t(P_{1,2\ldots ng})\big)^2 R_j = \frac{1}{2} * P^T * R * P$$

- Classical LR formulation with added heuristic
- Heuristic uses line loss penalty as an added cost for unit commitment
- The penalty is distributed appropriately using Generation Shift Factor and the line resistance
- The heuristic can differentiate between similar or identical units

Benchmark LR using MIP (Egret software)





- Units 1 & 3 are identical
- unit 1 is closer to the load center
- Unit 2 is the cheapest
- Unit 4 is the most expensive
- LR prioritizes unit 1 over unit 3
- Similar results with Egret

	Total Cost
Egret ($)	315,087.7
LR ($)	315,451.4

Transmission Constraint Penalty Using WECC 240 Bus System as a Test Case

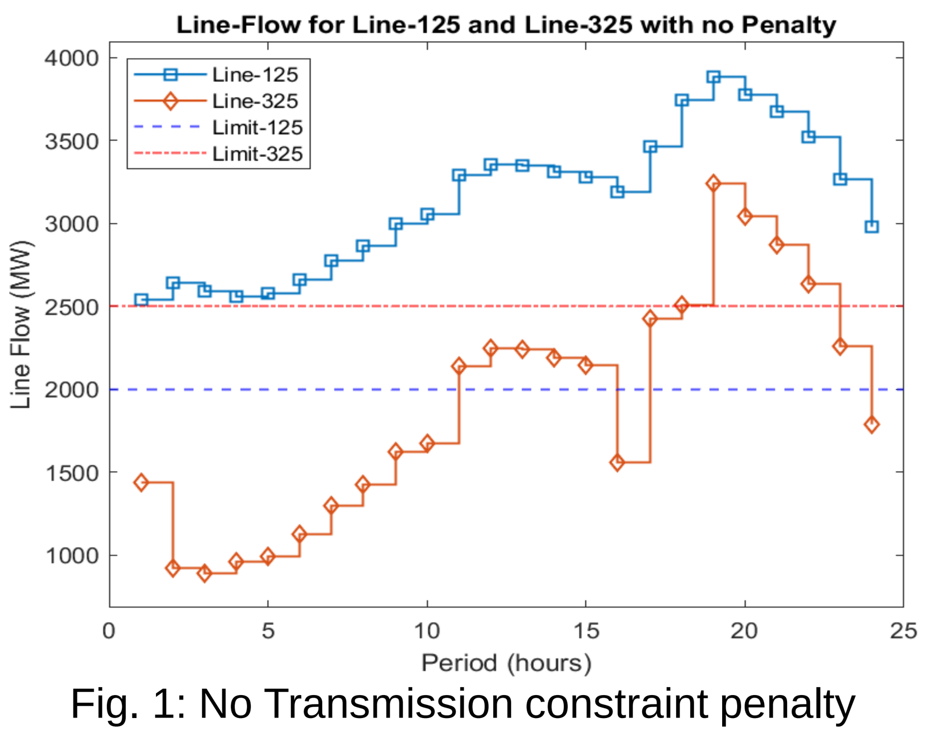


Fig. 1: No Transmission constraint penalty

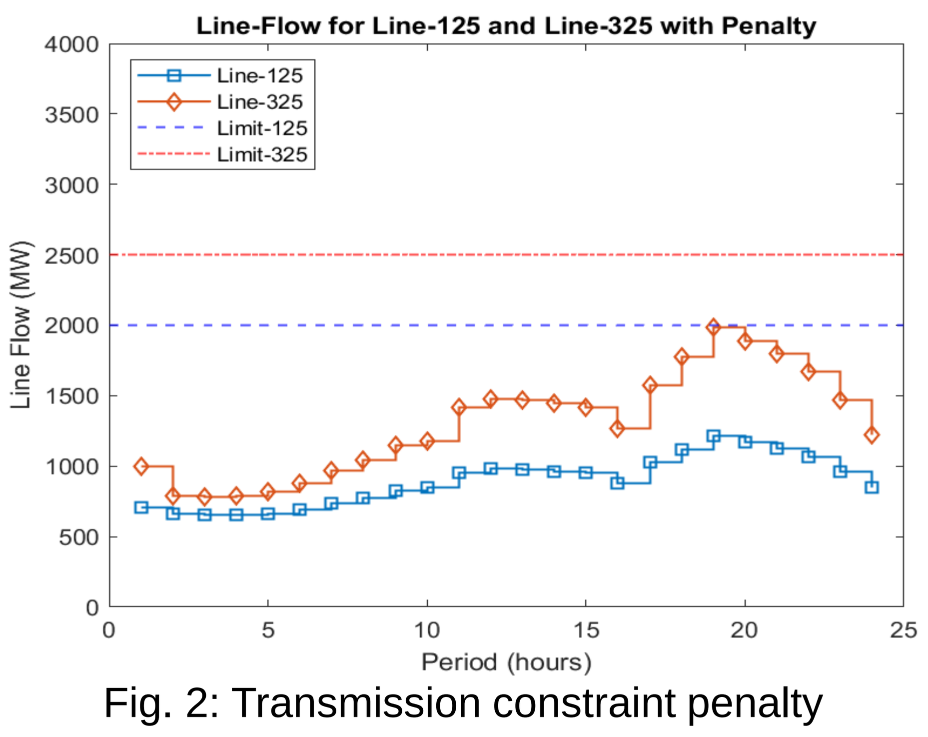


Fig. 2: Transmission constraint penalty

- A second layer of heuristic is targeted at lines with transmission constraints only
- Line flow limit 125 and 325 are both exceeded when there is no line constraint penalty (Fig. 1)
- Both line flows are kept below the flow limits (Fig. 2) at a scaling factor of 10

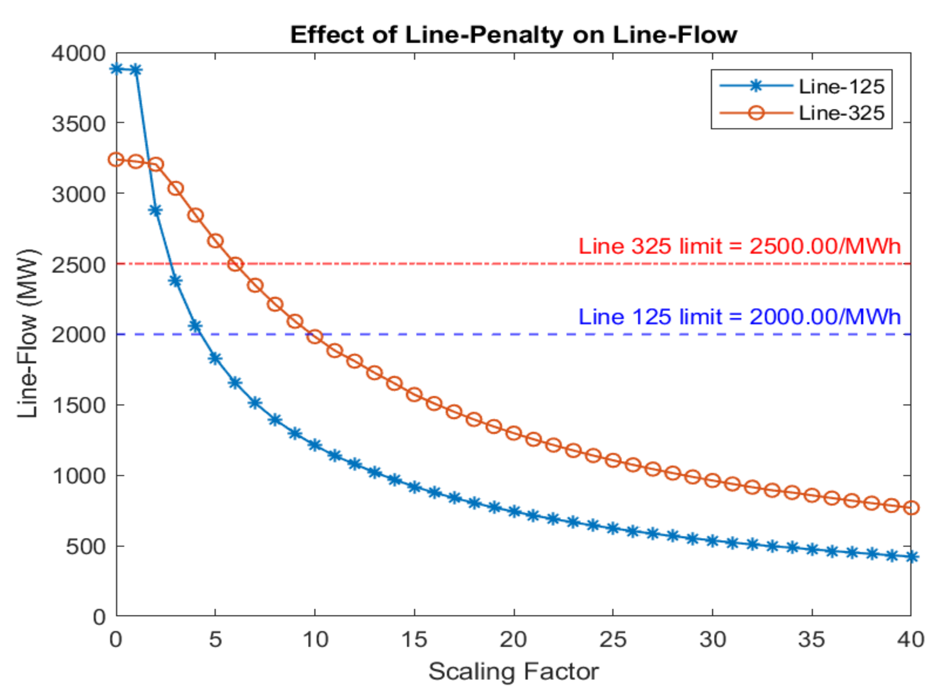


Fig. 3: Line flow as a function of penalty

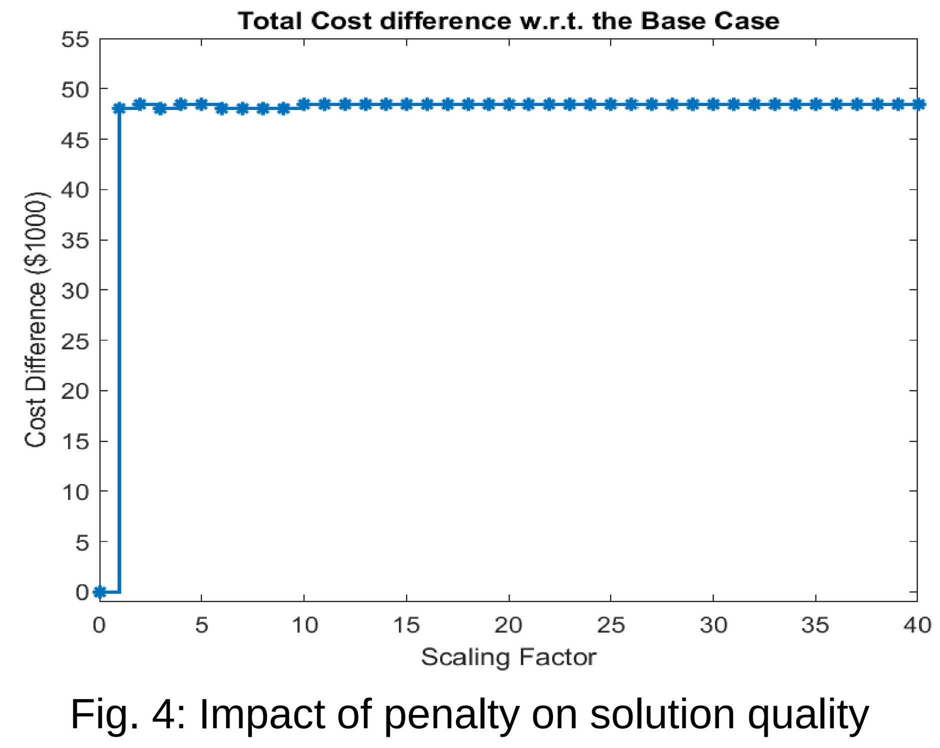


Fig. 4: Impact of penalty on solution quality

- At scaling factor 0, the penalty equals 0
- The flows in line 125 and 325 decreases as the scaling factor of the penalty increase (Fig. 3)
- When the penalty scaling factor equals 6, both line flows are below their flow limits
- The total cost of constraint settles down quickly at an average of $48,000 (Fig. 4)
- Considering the line flows and total generation cost, a good scaling factor is 6