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Decomposition Methods for Large-Scale Optimization of Power Systems

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Variable renewable power sources are being integrated into power systems across the world. This restructuring process requires extensions of most parts of the power system infrastructure: generation, transmission, as well as storage capacity. Joint optimization of infrastructure extension and operation is a powerful method to identify technical solutions with minimal economic costs. This optimization problem is often formulated in a simplified linear problem [1]. Even though the resulting linear programs can be passed to standard solvers, a challenge arises from the large dimensionality of the problems, especially if a high temporal and spatial resolution is desired.

These challenges are addressed in joint efforts by our two research groups, with complementary expertise in power system optimization and communication theory. We believe that applications of communications theory to modern power networks go way beyond the obvious exchange of grid related information, such as measurements or control commands. Instead, we conjecture that communications and power networks share some interesting structural similarities leading to analogies in the associated optimization problems. For both, power and communication networks, distributed solutions, based on optimization theory and decomposition methods, were introduced and are developed independently, see [2,3] for an overview and further references.

As a first result, we investigated the potential of decomposition techniques for the specific problem of joint optimization of system extensions and operation. As there are no systematic methods to find the best suited under the many decompositions possible, our experience in successful application of decomposition methods in communication networks was very helpful. We propose a primal decomposition to split the optimization into the problem of finding the cost-optimal grid extensions and the subproblem of optimizing the operation for given infrastructure extensions, which exhibits a network flow optimization structure that is frequently observed in communication networks [2]. By doing so, the grid operation can be optimized for each time interval separately, which leads to a significantly lower overall computational complexity and allows for parallelized implementation.

As the network structure and the production costs are identical for each time interval, the demand is the only difference. By using the dual LP formulation the relaxed demand constraint appears in the objective and the set of feasible solutions is identical for every time interval. A solution of a LP can be found at one of the finitely many extreme points. Therefore, every extreme point is a solution for a set of infinitely many possible objectives. The solution of a different time interval that has similar demands, can serve as an good initial guess. Although interior point methods are superior in many applications, we propose to use the simplex algorithm that heuristically computes a series of extreme points until a solution is identified by an optimality check. By initializing the simplex algorithm with solutions of a different time interval we are able to drastically reduce the number of extreme points to be computed. At best, the only cost is the optimality check for the intial guess if it is successful.

It remains to compute the optimal system extensions, which is a non-linear problem. A solution can be computed efficiently by polyhedral approximation of the problem, which is frequently applied for network utility maximization [4]. The solution of the approximated problem, i. e., a possible grid extensions, defines the network layout for the subproblems. The solution of the subproblems allows for a refinement of the approximation. By variation of the aggregation level we are able to gradually adjust a trade-off between number of subproblems to be computed and size of the approximated problem. For the colloquium, we intend to present a general overview on our research efforts as well as specific details on the methods developed for large-scale optimization of power grid extensions and operation.

References

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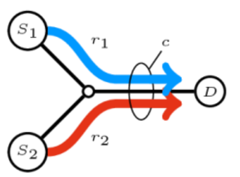


S_1, S_2 sources
D destination
$U_i(r_i)$ utility function
r_i rate emitted by S_i
c link capacity

Network Utility Maximization

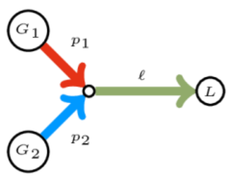
primal problem:

$$\underset{r_1, r_2}{\text{maximize}} \quad U_1(r_1) + U_2(r_2) \qquad \text{subject to} \quad r_1 + r_2 = c$$

dual problem:

$$\underset{\lambda}{\text{minimize}} \quad \lambda c - U_1^*(\lambda) - U_2^*(\lambda)$$

interpretation: dual variable λ is the price sources are charged for using the link



G_1, G_2 generators
L load
$C_i(p_i)$ cost function
p_i power output of G_i
ℓ total system load

Optimal Power Flow

primal problem:

$$\underset{p_1, p_2}{\text{minimize}} \quad C_1(p_1) + C_2(p_2) \qquad \text{subject to} \quad p_1 + p_2 = \ell$$

dual problem:

$$\underset{\mu}{\text{maximize}} \quad \mu\ell - C_1^*(\mu) - C_2^*(\mu)$$

interpretation: dual variable μ is the price paid to generators for inducing power

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