Coordinating Wind Turbines and Flexible Consumers with Cooperative and Competitive Agents

(Extended Abstract)

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1. INTRODUCTION AND PROBLEM

Meeting the 20-20-20 objectives put forward by the European Commission to increase the share of renewable energy production in Belgium to 13% of the gross final energy consumption, requires the installation of large wind farms both on- and offshore. Integrating these wind farms into existing distribution infrastructure is challenging because of potential congestion caused by imbalance between wind turbine energy production and consumers' energy offtake.

One technical constraints that needs to be considered is guaranteeing that existing cables can cope with the increased wind energy injection into the grid. Adding energy production elements to existing grids can cause power rates to increase past the rates that would ensure safe cable operation. Upgrading existing cable infrastructure to cope with increased power rates would lead to a costly replacement of existing cables. Experience in industrial projects shows that this is an actual problem DSO's are facing when incorporating wind turbines into existing distribution infrastructure. Considering that these excessive power rates only occur occasionaly, alternative remedies are investigated.

Literature describes ANM techniques for dealing with these forms of increased power production related current congestion in a more cost effective manner [3]. Active Network Management (ANM) techniques describe a class of techniques for actively performing steering actions in distribution network management to minimize congestion problems from excessive wind power production.

This work focuses on DSM as an ANM technique to resolve the problem of upstream current congestion. The distinction is made between two phases and we propose algorithms for both phases. The first phase deals with an ahead of time planning phase where grid investment or reinforcement has to be outweighed against demand-side management (DSM) [3]. A second phase considers a real time situation for online allocation of ANM resources based on local wind production forecasts. For online power flexibility allocation, two mechanisms, a cooperative contract-net based mechanisms and a competitive qualitative Vickrey auction (QVA) are implemented and compared in terms of allocative efficiency.

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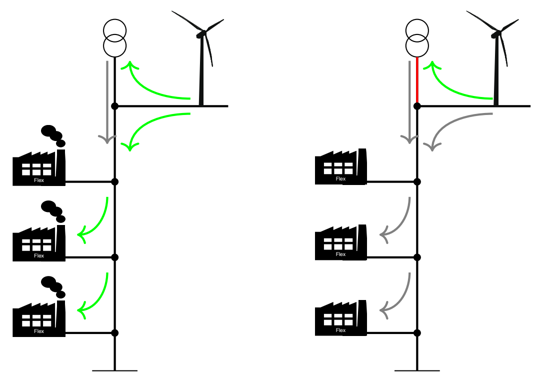

Figure 1: Example scenario for upstream current congestion. Left: Energy flows from wind turbine to factories downstream and all excess production flows upstream towards the TSO transformer for grid injection. Right: Factories downstream are inactive and all energy flows upstream towards the TSO transformer causing upstream current congestion.

2. REMEDYING CONGESTION

We focus on tertiary reserve under a dynamic profile (R3DP) as the closest matching real-world strategic reserve product that is relevant to this work because of its focus on flexible DSO-connected grid users. The flexibility product description that is used in this work is therefore proposed for DSO-connected grid users that offer consumption increase flexibility according to the following constraints, which are similar to the R3DP activation constraints specified by Elia, the belgian TSO:

- A maximum of 40 activations/year is allowed.
- All activations last max. 2 hours.
- The time between 2 consecutive activations should be at least 12 hours.

2.1 Offline Allocation

Primarily, an offline optimal solution can provide an upper bound on the maximum allocative efficiency that is attainable for given wind profiles and flexibility in the system, constrained by activation such as described in the previous section.

Optimally solving the allocation problem is done by solving a MIP model to maximize the remedied congestion over time $s(t)$ to maximize the efficiency of the allocation of the flexibility activation.

2.2 Online Allocation

For solving the real-time problem we study two different approaches to the flexibility allocation problem. A cooperative setting relating to current practice in industry is modeled. DSM participation is currently often regulated by contracts and these contracts are enforced with significant fines and complete exclusion from DSM programs. In response to state-of-art proof of concept cases, modeling flexibility market mechanisms where all parties act as market participants, a strategy proof, Qualitative Vickrey Auction (QAV) is implemented as a counterpart to the cooperative setting. Both approaches are evaluated in terms of allocative efficiency which is defined as the amount of excess energy that is actually reduced by a DSM activation. Any activation that leads to more energy reduced than the amount that was causing congestion is considered inefficient. Both mechanisms are implemented to follow a similar message protocol. Every time period of 15 minutes, the center agent evaluates whether forecasts show that congestion will occur and if so, will send out a *call for proposals* to all agents. Agents then respond with a bid depending on their capabilities at that time and the winning bid is sent an activation signal.

In the cooperative mechanism, the winner is determined by a social choice function $\mathcal{F}(R^n)$ which favors the closest bid that could resolve most of the congestion among all the bids. This function is defined in (1) where $C(t)$ is the function representing the congestion over time and $\epsilon(x)$ represents the allocative efficiency for that bid.

$$\mathcal{F}(R^n) = \underset{y \in R^n}{\arg\max}(\epsilon(y)) \tag{1}$$

$$\epsilon(x) = \int_{x_{start}}^{x_{end}} \min(C(t), x_p) dt \tag{2}$$

In the competative mechanism, contract auctions are implemented. Contract auctions are an application of Qualitative Vickrey Auctions (QVA) [2], which are known to be the only mechanisms that are individually rational, dominant strategy proof and capable of selecting stable, Pareto efficient outcomes given the assumption of weakly transferable utility [1]. The assumption of weakly transferable utility does not hold because the center has single (positively) peaked preferences which introduces a local maximum. Inspired by the work in [1], a fixed and publicly announced tie-breaking rule is used to guarantee strategy proofness in the absence of weakly transferable utility. In this case, however, Pareto efficient outcomes cannot be guaranteed, however.

3. EVALUATION AND DISCUSSION

The optimal full knowledge allocation approach can deliver very efficient allocations in general. The main drawback is that optimally allocating agent power flexibility over a one year time horizon in 15 minute increments, leads to very high resource requirements, in both CPU time and memory for the branch-and-bound technique used for solving MIP problems.

The first result is that attaining totally efficiency allocations is not possible in even the simplest case with 1 flexibility provider, using the optimal allocation algorithm. The observed mean efficiency from repeated simulations with 1 provider was 98.96% with no provider attaining 100%. Simulations with more provider yielded lower efficiency rates. Further study into the flexibility required to solve these specific current congestion problems is needed because currently available flexibility products can not be used to attain 100% efficient allocations in the best case scenario.

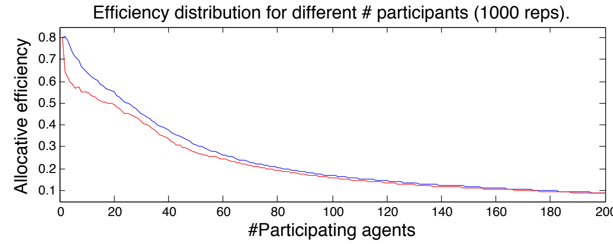

Figure 2: Results for up to 200 participating agents show higher mean allocative efficiency of the cooperative (blue/higher) setting when compared to the competitive (red/lower) solution.

The second result in Figure 1 shows that the cooperative approach manages to attain a higher allocative efficiency than the competitive approach. These results also indicate that the difference in mean efficiency between both approaches decreases significantly as the number of participating agents increases making the difference between the two approaches negligible in terms of result when many agents participate. Assuming that more than 10 agents would be located in such a way that they can all be used to resolve congestion is, however, unreasonable because all agents need to be connected to the same feeder, as is illustrated in Figure 1.

4. CONCLUSION

This work presents initial findings in a study to apply cooperative and competitive MAS techniques to the problem of upstream current congestion. Further results analysing different metric and different wind profiles are underway.

Further work is necessary to specify the exact flexibility product requirements that are necessary for dealing with these current congestion problems. In future work we will also analyse investmentment costs and compare these costs to other ANM techniques such as storage.

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