Flexible Assets Bid Across Markets

Final public project summary

Funding programme

Topsector Energie (TSE)
TKI Urban Energy - programme line 5. Energieregelsystemen en –diensten.
Call of September 2017

Project

Title:	Flexible Assets Bid Across Markets
Acronym:	FABAM
Start:	1 April 2018
End:	31 March 2021
Reference:	TEUE117015

Consortium

Vattenfall Flexibility Services (VFS, project lead)
formerly Senfal Energie Nederland B.V.
contact: Nienke Hosman, nienke1.hosman@vattenfall.com, Product Owner VFS

Intelligent and Autonomous Systems research group (IAS)
Centrum Wiskunde & Informatica
contact: Michael Kaisers, Michael.Kaisers@cwi.nl,

This project has been executed with Topsector Energysubsidy of the "Ministerie van Economische Zaken en Klimaat"

Project summary and results

Summary

In the 3-year FABAM project, CWI and Senfal / Vattenfall have developed a system for energy asset optimization with advanced planning and modeling capabilities, and successfully tested it in real world situations. The results of this project include published papers on planning theory, and energy optimization software that is used for actual customer services. Both on the theoretical and on the practical side there are a number of lessons learned, and some interesting directions for future work.

Introduction

This project has been defined in 2017 as a collaboration between CWI, a Dutch research institute with a deep background in fundamental research on energy adaptivity, and Senfal, a startup in the field of energy flexibility aggregation.

Senfal was increasingly discovering that bidding individual smaller-scale assets to individual energy flexibility markets was leading to inefficiencies and high cost for creating one-off solutions. Many of the common markets have minimum bid sizes of 100 kilowatt-hour or even 1 megawatt-hour which prevents many individual assets from being connected at all. At the same time many solutions for flexibility optimization were market-specific. This made it costly to switch between markets to adjust to fluctuating market prices.

These challenges led Senfal to look for a solution to aggregate assets, even of different types, together and to bid their flexibility to multiple markets in a cost-effective manner. Such a solution would have to be much more dynamic than the previous generation of single-asset single-market solutions, and would thus require quite advanced planning capabilities (to dynamically adjust to changing circumstances) and modeling capabilities (to group assets of different types together, and to switch between different markets, in an efficient manner).

CWI had previous experience with creating Anytime Online Planning systems, and suggested to apply amongst others Monte-Carlo Tree Search, a powerful general planning algorithm, to this problem space in order to create a sustainable system for maximizing the value of energy flexibility.

During the run time of this project Senfal was acquired by Vattenfall. After the acquisition the project continued as planned, and there appear to be opportunities to apply the project results on a wider scale within Vattenfall.

Objective

The project plan outlines the following goals:

- Mature the anytime online planning approach (specifically Monte Carlo Tree Search) to optimize intertwined market commitments and real-time control decisions, thereby maximizing the value of flexibility;
- Implement the modular FABAM system to apply the approach to allocate energy flexibilities efficiently ('ontsluiting van flexibiliteit');
- The resulting system should be 'deployable', i.e. actually usable and stable;
- Test the performance with real data in laboratory and operational conditions.

The project plan did not include explicit assumptions, but is clearly based on at least these implicit ones:

- Monte Carlo Tree Search is a suitable algorithm for solving typical energy optimization problems;
- Other projects will provide sufficient assets to test the FABAM system (the FABAM project plan itself did not include any work packages aimed at creating pilot setups).

Method

In line with the funding programme call, the project was structured from the start as a mix of a research project - with specific research questions outlined in the project plan - and a software development project - with high level technical target capabilities similarly outlined.

The work was divided into work packages, with the following broad responsibilities assigned:

- CWI would be responsible for:
    - Creating a suitable planning algorithm
    - Theoretical planning / optimization research
- Senfal (later Vattenfall) would be responsible for:
    - Creating domain models for assets and markets
    - Providing assets and business cases to test with
    - Providing the required IT infrastructure (e.g. market data, connections to markets, connections to assets etc.)
- Both parties would be jointly responsible for:
    - System design
    - Testing and evaluation

This structure as set out in the project plan turned out to be quite usable during project execution and there has been no great need to deviate from it. In fact the only significant deviation from the project plan was requested right at the beginning, when a delay of 2 months in both the project start- and end dates was requested from RVO, and granted.

To structure software development even further the SCRUM methodology has been used. The research has been conducted iteratively, by 1) identifying shortcomings of existing state-of-the-art sample based planning algorithms and their applicability to flexibility allocation as foreseen in this project, 2) isolating and addressing individual improvements in a controllable setting, and 3) communicating progress within the project and publishing results.

Results of the project

During the project virtually all work packages were successfully completed. This led to the following 'tangible'[1] results:

- Multiple iterations of a design for the FABAM system as a collaborating planning module and world / domain model, including standardized APIs and an automated reward and evaluation system;
- A benchmark planning algorithm based on simulation of genetic evolution (genetic algorithm);
- A benchmark domain model for a residential house with electrical heating;
- A scalable and deployable planning algorithm based on Monte Carlo Tree Search (MCTS);
- A domain model for an actual e-boiler ('waterbatterij'[2]) located at the Willem van Oranje College (a high school) in Waalwijk. Together with the MCTS planning algorithm this forms a robust planning system that can adapt dynamically to changing circumstances in the energy markets;
- A domain model for a micro-CHP;
- An integration of the FABAM planner and domain models into the Senfal 'Senbi/Flex' Energy Management platform (which provides the actual market and asset connections);
- A more advanced domain model for a setup like at the Willem van Oranje College, with e-boiler and solar panel assets, and both day-ahead and imbalance markets all interacting;
- A simulation and evaluation framework for running the FABAM system at accelerated speed with a set of historical data;
- Various evaluation results, both theoretical and in the practical setting of the Willem van Oranje College (some of these are included in later sections of this document);
- A shared source code repository;
- Various published papers (see the references at the end of this document).

Possibilities for broader application

Although the developed domain models are somewhat specific for the particular customer situation, the planner software and also the development methodology are reusable, and applicable to a wide range of energy optimization problems, both within Vattenfall and in the broader energy sector. The planning methodology has been publicly disseminated via research publications.

---

[1] Results that, although in digital form, can be demonstrated, read etc.

[2] This is where this FABAM project has touchpoints with the Waterbatterij project, also subsidized by RVO, but with a different project consortium. Although the projects were executed independently there were certain synergetic effects; the pilot setting that was created as part of the Waterbatterij project in Waalwijk was selected as a useful test setup for the FABAM project, and in the end after evaluation a simplified version of the FABAM system was selected to provide the market access planning in the Waterbatterij project (although Senfal has developed a simpler system that would achieve the same results in the Waterbatterij project).

Bottlenecks
During the project some bottlenecks were identified. These do not negate the value of this planning technology, but should be seen more as improvement points to be addressed in the future. The specific bottlenecks are:

- This technology is complex and is most suitable for complicated customer situations with multiple assets and multiple markets. These situations are relatively rare, and at the current maturity level of the energy flexibility landscape it often makes sense to start with basic optimizations of single assets and markets. In this sense the problem that was foreseen before the start of this project turned out to be less common than expected, and the market turned out to be maturing slower than hoped.
- There are competing technologies aimed at the same problem space. For example, within Vattenfall a technology based on linear programming and the commercial Gurobi software package was developed, and this is also used for complicated optimization situations.
- This planning technology depends heavily on the quality of the domain model that is developed. Developing such models requires skills that are rare and hard to find in the recruitment market for software developers;
- The used MCTS algorithm is most commonly used for discrete problem spaces (where control actions are clearly distinct). However the actual problem spaces found in the energy realm are often of a continuous / non-discrete nature (where actions are taken along a broad range of values such as bid prices or activation percentages). Adjusting MCTS to continuous problem spaces is still an on-going research topic.
- Like many AI technologies, the MCTS algorithm is not by itself able to explain its actions to interested human observers. This makes it hard to confidently say something about the quality of the solutions that the algorithm generates. In fact such explanation strategies are another on-going research subject, with some initial solutions provided in our publications about explainable AI.

Possibilities for spin-off and follow-up activities

The developed FABAM system is quite a generic energy planning / optimization module, its spin-off and follow-up activities are already covered in the previous section (‘possibilities for broader application’).

With regards to the theoretical work, each publication addresses the specific contributions and potential follow-up work. However, the project also identified two challenges that require significant additional work to close the gap between theory and practice. The immense progress on solving discrete time decision tasks with AI in general, and with optimisation, planning and learning in particular, has yet to be translated to planning for complex distributed real-time systems. This suggests follow-up research, improving sample based planning to address the challenges of continuous time and combinatorial action spaces.

Discussion

The broader value to society of this technological development can be seen as follows:

- The FABAM system is able to efficiently combine assets and choose between market opportunities, allowing the asset owners to receive a higher than usual price for their flexibility. This is equivalent to saying that such assets are then more closely connected to market signals. When applied to renewable assets this clearly boosts sustainable energy management, and directly improves the ROI of such assets.
- When the FABAM system is applied to non-renewable assets this still increases the effective amount of flexibility available in the grid (e.g. to be used by TenneT for balancing), which allows more renewables to be added and then other (non-flexible) non-renewable assets to be taken offline.
- The e-boiler and solar panels that were used as a test setup at the Willem van Oranje College in Waalwijk are a good example of how such a system contributes to sustainable energy management: this setup is quite complicated because it is added 'in front of' an existing gas-based heating installation. The FABAM system here enables cheap charging of the water battery by using power from the solar panels and from imbalance price dips (i.e. surplus moments on the energy grid). This warm water is then used as much as possible, lowering the number of hours that the gas boiler has to run, and making the complete heating system at the College more sustainable through this advanced FABAM planning system.
- The papers that have been written and published clearly strengthen the knowledge position of the energy optimization research community and the Dutch energy sector.

Lessons learned

- FABAM is a powerful planning tool, which is most suitable for complicated planning problems. For simple problems it involves an overhead which is somewhat impractical.
- The explainability of FABAM-like technologies is not yet sufficient for practical application (from Vattenfall point of view this is more of a concern with external customers than with internal ones, which are more easily satisfied with a good revenue improvement and more comfortable with probabilistic control systems).
- Even in an agile environment it pays to spend some time to set up multi-year projects properly with a project plan, work breakdown and clearly assigned roles, assuming that the problem area is sufficiently understood.
- In multi-year subsidy projects it is easier to adapt to assets and customers that become available along the way (outside the project itself) to test the developed systems, instead of forcing the development of pilot setups inside the project (this lesson was learned when comparing FABAM to some of the other subsidy projects in which Senfal participated).

Changes compared to the project plan

There were a few mostly administrative changes in the project, in particular at the beginning:

- The project start and end date were delayed for two months to allow for more time to set up the proper resourcing for the project;
- Senfal was acquired by Vattenfall, with some name changes of the involved legal entity;
- The involvement of EV Box and HDSR was replaced by Matojo and AE Magnetic. (As these were not direct project participants but rather parties involved at a distance this did not require a change in the project plan).
- No web site dedicated to the project was created. On Senfal side this was partly due to the acquisition by Vattenfall, which made it hard to 'claim' a part of the Vattenfall web site to publish about a Senfal project. On CWI side this was compensated by the publication of a significant number of papers based on the project work and findings.
- One of the deliverables out of the initial Project Plan, being a financial impact analysis, could not be delivered as part of this end report. The reason for this is that there is not enough data yet on which we can base such a financial impact analysis. This is in parts due to organizational changes and circumstances that lead to the fact that the Water Battery is not yet operating at a level where we can derive enough data from it. Furthermore, the project identified and addressed additional challenges of bringing sample-based planning to the setting of distributed smart energy control, necessitating the conducted project work that had to precede financial analysis.

Method of dissemination of knowledge

As discussed above, knowledge has been disseminated publicly primarily through publishing papers on the project work and findings (from a theoretical perspective). It is additionally thought that the public final project report will be a useful way for interested parties to learn more about the project and its results.

PR project and further PR options

For Senfal / Vattenfall this has turned out to be a useful component to support increased asset profitability (flexibility projects are often executed on a profit share basis, so that the majority of the increased profitability will then flow to the customer, and a smaller part to the company providing the trading / optimization services). The capabilities to support these complex set-ups are advertised under names such as 'Industry Flex Manager' (https://energysales.vattenfall.de/smartconnect-en), although this name covers a broad set of technologies and algorithms, not just FABAM. However as explained elsewhere in this document the commercial projects that have sufficient numbers of assets / asset types and markets to profit from the FABAM approach have so far been limited.

For CWI, the research publications on planning methods provide a means to attract attention to its research, and a number of them have been presented at scientific workshops and conferences.

- At AAMAS 2020, May 9, 2020 [5]
- At CoG 2020, August 26, 2020 [1]
- At FDG 2020, September 15, 2020 [2]
- At IJCAI 2020, January 8, 2021 [3]

- At AAAI 2021, February 8, 2021 [4,10]
- At AAMAS 2021, May 3, 2021 [8]
- To be presented at GECCO 2021, July 10-14, 2021 [7]
- To be presented at IJCAI 2021, August 21-26, 2021 [6]

The FABAM project and associated research has also been presented to the research community at invited talks and group seminars.

- At the School of Electronic Engineering and Computer Science, Queen Mary University of London, April 30, 2019
- At the Department of Intelligent Systems, Delft University of Technology, November 27, 2020

Research publication summary

The theoretical work at CWI had the high-level goal of developing suitable algorithms for the specific challenges foreseen for the FABAM system. This meant improving the performance of anytime online planning in the Monte Carlo Tree Search (MCTS) framework, in particular in complex search spaces such as those created by combining multiple assets or agents in one planning system. These agents all have to be controlled separately, which leads to combinatorial growth of the planning problem - to combinatorial action spaces.
The overall approach chosen to tackle this problem in the FABAM project was online generalization or abstraction, aiming at uncovering and exploiting different types of useful and simplifying structure in the problem. In addition, human understanding of MCTS decisions was identified as an issue during the project, and led to a parallel line of research into explainable AI (XAI).

In [1] and [2], we used multi-player games as test domains in order to explore these issues, leading to two different abstraction approaches that speed up search by focusing the attention of the search algorithm on the most relevant actions. This was achieved in [2] with a dynamic and fine-grained method for pruning the search space as much as possible without reducing solution quality, abstracting away much of the complexity of introducing additional agents by ignoring their actions that are less likely to influence the optimal plan. In [1], using specific properties of MCTS, we refined this idea to create a search process that does not simply prune actions judged less likely to be relevant, but instead simultaneously comes up with a faster, less precise plan using abstraction over most agents' actions, and a slower, fully accurate plan without abstraction, guiding the latter through the former, and moving seamlessly from the former to the latter depending on available planning time.
We further generalized this line of research in [6] to create an MCTS search that can integrate different types of abstraction or generalization into one and the same planning process - not just abstracting over potentially irrelevant other agents and their actions, but also over potentially irrelevant aspects of the state and action space itself. To guide search in the vast state-action spaces that arise in combinatorial allocation problems, we incorporated and tested concepts of novelty search in MCTS, building again on the evaluation framework of games as an established research testbed for progress on such algorithms [7].

Planning requires a model of the system to plan for, and in practice any such model may bear some errors – deviations between the model and reality. In critical systems, such as energy allocations in power grids, it is desirable to find solutions that not only perform well in expectation, but are robust to a certain limited set of errors. We therefore explored the extension of our MCTS planning approach towards robust online planning [8].
In [5,9], we additionally focused on further developing state-of-the-art MCTS planning approaches that self-improve via the integration of deep reinforcement learning, which we consider a powerful possible future extension of the FABAM system. Furthermore, we recognized a need in energy systems to provide robust solutions that insure a certain quality in spite of some gaps between theory and practice. Such gaps may arise due to modelling errors or adversarial or erroneous components. We published initial results of this research on robust temporal difference learning, in which we improve learning strategies for distributed systems that optimise performance in face of individual component failure or adversarial deviations [10].

Publications [3] and [4] finally deal with the problem of explainability of algorithmic decisions, which increased in relevance during the FABAM project both in our practical experience as well as in the wider AI community. A planning system that cannot explain the reasoning process behind its decisions poses a challenge both for developers trying to debug and improve it, as well as for end users who need to build trust in and successfully work and collaborate with it in practice. In [3], we therefore formulated and detailed the research vision of Explainable Search as a challenge to the research community. In [4], we reported on our first working implementations that are able to translate large and complex search trees filled with sample statistics and confidence intervals to human-understandable summaries and explanations of possible futures and the actions planned for them.

Conclusion and recommendations

This project has shown that with concerted effort research and engineering can be combined to create an advanced energy flexibility planning and optimization system. As this field is still quite new at the moment it is not always easy to explain the advantages of such a system to prospective customers. Still, this kind of system is specifically suitable to manage the large scale asset pools that increased electrification and increased shares of renewables in the energy mix will bring us.

It is recommended to support more research and development in this field, in particular aimed at managing large scale asset pools, for example EV charging stations, combined with challenging energy markets such as the Intraday and aFRR markets. In addition more work is needed to allow such software systems to properly explain their actions.

Acknowledgement

The project was carried out with subsidy from the Dutch Ministry of Economic Affairs, National schemes EZ subsidies, Top Sector Energy implemented by the Netherlands Enterprise Agency (RVO).

References

[1] Hendrik Baier and Michael Kaisers. Guiding Multiplayer MCTS by Focusing on Yourself. In IEEE Conference on Games (CoG 2020), pages 550–557, 2020.

[2] Hendrik Baier and Michael Kaisers. Opponent-Pruning Paranoid Search. In Foundations of Digital Games (FDG 2020), 2020.

[3] Hendrik Baier and Michael Kaisers. Explainable Search. In IJCAI-PRICAI 2020 Workshop on Explainable Artificial Intelligence (XAI), 2021.

[4] Hendrik Baier and Michael Kaisers. Towards Explainable MCTS. In Workshop on Explainable Agency in Artificial Intelligence (AAAI-XAI), 2021.

[5] Daniel Willemsen, Hendrik Baier, and Michael Kaisers. Value targets in off-policy AlphaZero: a new greedy backup. In Adaptive and Learning Agents (ALA) Workshop, 2020.

[6] Hendrik Baier and Michael Kaisers. ME-MCTS: Online Generalization by Combining Multiple Value Estimators. In print, in International Joint Conference on Artificial Intelligence (IJCAI), 2021.

[7] Hendrik Baier and Michael Kaisers. Novelty and MCTS. In Evolutionary Reinforcement Learning Workshop (EvoRL), 2021.

[8] Maxim Rostov and Michael Kaisers. Robust Online Planning with Imperfect Models. In Adaptive and Learning Agents Workshop (ALA), 2021.

[9] Daniel Willemsen, Hendrik Baier, and Michael Kaisers. Value targets in off-policy AlphaZero: a new greedy backup. Neural Computing and Applications, in print, 2021.

[10] Eleni Nisioti, Daan Bloembergen, Michael Kaisers. Robust Multi-agent Q-learning in Cooperative Games with Adversaries. In AAAI-21 Workshop on Reinforcement Learning in Games (RLG), 2021.