# Agile development process and user-centric data driven design for an integrated energy system

# Agile Development Process and User-centric Data Driven Design for an Integrated Energy System

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***Abstract*—Now the design of energy system requires need-owners to play an active role by using advanced technical solutions to improve their responsiveness, process adaptability and empower end-users. Although need-owners via Demand Response (DR) has gain sufficient strategic improvement in energy management recently, there are still some fundamental impediments to achieve a trade-off between demand flexibility scheduling and dispatch. To find a solution to the challenge, the paper introduces the steps of an agile development process for energy systems, refers to a co-creation of solutions based on co-existing technologies and iterative development, where need-owners requirements and solutions evolve through collaboration between cross-functional intelligent agents. The proof-of-the-concept is investigated by agent-oriented simulation for a generic low-voltage network of the Netherlands, which encounters transformer congestion. Simulation results reveal a significant reduction in congestion over a year while confirming expected levels of performance.**

***Index Terms*—Agile development process, User-centric Data Driven Design, Integrated Energy System, Multi-agent System.**

## I. INTRODUCTION

The high penetration of distributed energy resources (DERs) and an increase in domotics is a big challenge to the future energy systems. Numerous strategies have already been investigated to empower the need-owner and improve operations at low-voltage (LV) level. The price-based strategies are used by need-owners to engage end-users to schedule their demand flexibility [1]–[4]. Although the price-based strategies by need-owner empowers the end-users by providing full authority and willingness to its demand flexibility, due to no feedback the strategy lacks in responsiveness. Thus, the methods based on such strategy can not achieve process adaptability.

On the other hand, The incentive-based strategies are used by need-owners to engage end-users to dispatch their demand flexibility during operational hours. The strategy provides a process to achieve similar effects by combining direct and dynamic pricing methods with more end-user responsiveness in real-time [5], [6]. For instance, recently transactive energy is proposed to empower end-user with a local market framework incorporating day-ahead and real-time operations [7] that aims to minimize the cost of network support through the voluntary participation of the end-user.

Therefore, a strategy is required that coexists a multi-dimensional integration of digital technologies for decentralized energy resources, innovative business models for multiple economic sectors, and contemporary societal trends. Moreover, a strategy co-creates solution that brings a specified need from direct end-users which in turn creates new ideas to the system. This necessitates the agile development in energy system. The agile development was first coined in power system by Paul A. Centolella in 2012 [8]. It states that in agile development, the end-users are empowered by sharing opinions via real-time data and need-owners set priorities to increase total social welfare, thus there is a need of process which develops a bottom-up approach to have a deep understanding of problem and targeted end-user(s).

To achieve a specific objectives, this paper contributes by defining the steps of an agile development process for energy systems:

- Addressing critical drivers for need-owners and mapping the enablers required for the transition of local communities into an integrated energy system.
- Enhancing a multi-layer Model for the commercialization of the proposed services considering social acceptance, regional market constraints and the competing entities within the market.
- Formulating multi-agent based system for control and communication frameworks for faster and wider adoption of the proposed strategy within different societal levels.

In short, this paper, as shown in 1 shows that agility can be achieved in a DR paradigm by increasing the collaboration between the customer enabling, the strategic processes and the technologies. The EU Commission's legislative proposals within the winter package are ready to make transitions from the existing DR paradigm to the stage of agility. It can be inferred from the radar graphs that the Member States in the intermediate and mature group have already reached the stage of opportunism. Because they have already provided industrial, commercial and domestic customers with opportunities to use ICT effectively and explore DR services provided by an

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aggregator.

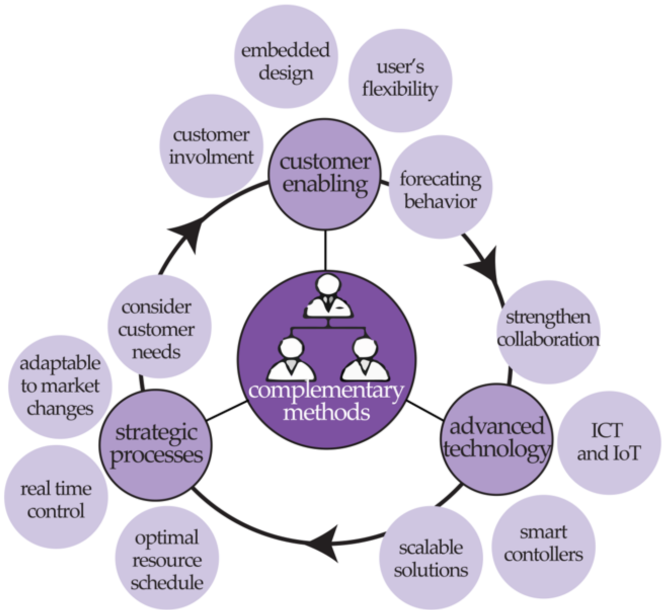


Fig. 1. Agile Development Process and User-centric Data Driven Design for an Integrated Energy System

Thus, the paper is organized as follows: Section II presents an overview of the agile development along with the agility enablers, drivers, and outcome, Section III which describes the methodological formulation of the agile development process. Section IV provides the description of the test network and the associated numerical assumptions. Furthermore, it also discusses the findings of the numerical simulations. Finally, section V concludes the results with some future recommendations.

## II. The Agile Developemnt

This section elucidates agility in the context of energy system as an ability of an need-owner to act in a competitive market environment either independently or via aggregator with an objective through the continuous learning process, and advanced information and communication technology (ICT). This perception is usually referred to as agile development process, which can be further envisioned from the essential elements of agility, i.e., agility driver, agility enablers and agility outcomes that are as follows:

### A. Drivers

With the advancements in smart grid technologies, including advanced ICT infrastructure, IoT, DERs, domotics and local flexibility markets, have been driving innovative ideas for research and development. Researchers have been incorporating the demand flexibility from domestic consumers/prosumers through transactive energy frameworks with different scopes and aims [6], [9]. Moreover, retail electricity markets have already been identified as one of the most promising alternatives for ancillary services like overall system balancing [10], [11] and network congestion management [12], [13].

Thus, these recent research and developments are the driving pathway to the agile development for the energy system, e.g., a paradigm complementing a transactive energy and blockchain for the decision-making process.

### B. Enablers

Agile development contributes in four research directions by enabling their respective competencies therein.

*1) Open and expendable architecture:* In the agile energy-system development, the architecture should consider the three research layers of need-owners, service providers, and end-user technology as guidelines to accelerate the deployment of integrated energy system solutions considering the scalability, replicability and contribution to the fundamental transformation process. In the literature, the agility in energy sytem are envisioned by a multi-agent system which can be easily co-create different strategies and technologies [6].

*2) Well-defined performance and scalability:* The peer-to-peer agent networking allows the agile development to be highly scalable as many agents can be easily integrated to handle multiple tasks and objectives. In this way, it can distribute its resource pool to accommodate updates and expansions regarding distribution network and aggregator(s). Herein, the minimum possible agents are assumed to achieve distributed system scalability in energy management. These agents are grouped into four broad categories depending on their assigned tasks.

*3) Fast and easy to learn:* Unlike model-driven learning and approximation [14], the researcher, thereinbefore, has a little insight into the formulation of data-driven learning for energy management. To conceptualize the end-user centric data-driven design, the agile development requires the end-user behavioural learning to support need-owners in their problem solving. An end-user behavioural learning is refereed to as virtual because the end-users' data drives the learning instead of its technical modelling. It also makes an architecture open such that it can easily visualize any end-user by enhancing an iterative learning process. In this way, need-owner can have an insight into the end-user data both off-line or on-line to act more efficiently and accurately.

*4) Incentivization:* Incentivization is the process of making value-based compensation to the end-owner(s). The proposed process should have value propositions (like price–signals in transactive energy) for incentivization. These propositions can also act as a unified information sharing mechanism for the need-owner to involve more and more end-users in their agile development process.

### C. Outcomes

The outcome of agile development is to present a milestone in the development of user-centric data driven techniques for real-time problems using advanced ICT. The energy system is referred to as agile energy-system because it inherits agility, i.e., being fast, scalable, easily integrated and intelligent in network management. With this consideration, the paper majorly contributes to the actual design and development of agility methodology.

TABLE I
SUMMARY OF AGILE DR STRATEGIES, EXISTING PRACTICES AND REFERENCES

| Strategic Area | Agile Practices | Ref. |
|---|---|---|
| Technologies<br>Systematic implementation and integration of smart design, devices and technologies. | Distributed automation and control<br>Aggregating and matching<br>ICT Infrastructure<br>Monitoring and Diagnosis | [15], [16]<br>[17]<br>[18], [19]<br>[20] |
| Integration<br>Practices relating to the development of mechanisms for integrating and coordinating the value chain, based on operations amongst DR participants and other stakeholders. | Demand Response Exchange<br>Transactive Control<br>Demand flexibility market<br>portfolio management | [21]<br>[22], [23]<br>[24], [25]<br>[26], [27] |
| Systematization<br>Practices to develop new products and/or process leading to standardized or systematized engineering. | Framework<br>Tool development<br>Standard development | [28], [29]<br>[30], [31]<br>[32], [33] |
| Knowledge Management<br>Practices relating to learning-based systems and learning. | Global access to data and information<br>learning organization<br>Distributed learning<br>Deep Learning | [34], [35]<br>[36], [37]<br>[6]<br>[38], [39] |
| Customer empowerment | Internet of things | [40] |

## III. AGILE METHODOLOGY

A conceptual agile methodology is encapsulated in three essential elements of agility: drivers (environment), enablers (agility practices) and outcomes. The conceptual model as presented in I, in a general way, captures the full integration of:

- customer empowerment;
- the use of smart design, devices, and technologies;
- integration of operations, with markets and customers;
- systematized engineering; and
- knowledge management.

It has been inferred that retail pricing is the pre-requisite and the most critical driver for the development of the Agile methodology. However, it is found that in the light of existing agility enables a methodology along with DR strategies can be complemented to build the Agile methodology. In last, it is expected that the paradigm will boost agility outcomes, i.e., DR strengths including energy cost, power quality, demand flexibility, demand dispatch and market responsiveness.

To be precise, this section contributes to the technical literature as follows:

- In principle, the methodology taps the potential demand flexibility from the participating customers and maximizes social welfare of a community in an unbundled electricity market.
- The Three-Layered Hybrid Architecture of MAS will allow agents to systematize and integrate into a distributed fashion for the agility goals and the TCM objectives.
- The concept of Micro-modeling of the agile methodology with multiple agents is introduced.
- It has been argued that the composite bid can integrate the customer preferences efficiently and control space (i.e., refers to primary process parameters) into control strategies for DR. The control space by the agents in the access layer are explicitly modeled regarding the composite bid.
- Finally, the principle of distributed learning, instead of centralized, is argued to be the most suitable methodology. Because it enables interactions between agents distributed within the layers to monitor, learn, schedule and dispatch the demand flexibility. Later, in the dissertation, it will be discussed that a methodology also reduces the learning complexity and computational time.

Although this section, in general, contributes to the evaluation of the agile methodology, this paper in specific has two main limitations. The first limitation is about DR strategies. In the literature, there are numerous studies which validate and verify that some DR strategies can be used to achieve the same objective. Therefore, this papers receommends a transactive-based control mechanism using the Multi-Agent System. The proposal for the design and development of Agile methodology is found fair and acceptable as per recent agility practices and enablers, as shown in I. The second limitation is about knowledge management and learning. Similarly, multiple methodologies can be applied to implement a learning-based system. In [40] have already discussed many existing options for knowledge management in DR. However; there are a few pieces of evidence related to the implementation of learning within the system. In this dissertation, for the proof of concept, a specific IoT platform is used for knowledge management and learning. Therefore, learning-based system, can be marked as a limited edition for the development of Agile methodology. Moreover, it validates essentially the blueprint of a system which is also expandable to advance options.

Nevertheless, in [6], the detailed micro-models of agents will be formulated as methodology advances regarding the agility goals and the TCM objectives. Moreover, the composite bidding rules will be used to systematize the bidding process throughout the strategic design and development.

## IV. IMPLEMENTATION

With the aim of providing tool support to the methodology, an object-oriented approach is presented herein. Alongside the requirement for the multi-layer architecture, the use of a knowledge-based ontology (as shown in 2) mitigates the effort required for the standardization of strategies for the agile development.

User-centric data-driven modelling within agent-oriented programming is instantiated with specific agents and their interactions to create a comprehensive knowledge base. 2 shows the knowledge based ontology of the agile development process for energy system. proposed in [6]. The ontology is specific to an objective of transformer congestion mitigation, as DSO being an need-owner.

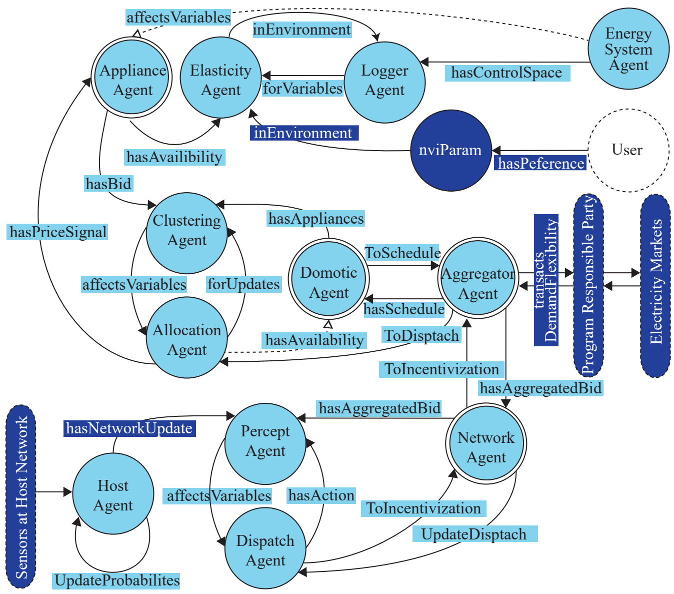


Fig. 2. Knowledge-based ontology of the agile development process for energy system.

Although the section only shows some agents that might be required to achieve business objectives of a DSO, the detailed data-driven of the agents within the paradigm are discussed in [6]. Briefly, appliance agent and its instances (i.e., Logger and Elasticity agents) are data-driven modelling for communication layer. They altogether represent the DERs. On the other hand, intermediate agents (like allocation, grouping, percept, and dispatch agents) are data-driven modelling for the information layer because they receive data of DERs and send information to the aggregator or network agent or both. An aggregator agent(s) (i.e., data-driven modelling at functional layer) is to provide solutions to improve the end-owners responsiveness. On the contrary, the network agent(s) can be identified by the DSO to increase process adaptability. Collectively, the objective agent(s) has a responsibility to achieve agility by co-creating the strategies, to empower the end-users in the energy system.

### A. *Overall Performance*

The overall performance of agile development process is evaluated through eight parameters, as shown in Table II. For an overall performance analysis, simulations are performed for a time window of a year on the data received from a Dutch Network Operator for a LV network. These performance indicators reveal the efficacy of the approach for mitigating the congestion while maintaining the reliability of supply. To better understand the performance, three variations of were

TABLE II
OVERALL PERFORMANCE SUMMARY

| Performance Measures | Case#1 | Case#2 | Case#3 | Case#4 |
|---|---|---|---|---|
| Max. congestion duration (hrs) | 3.75 | 2.25 | 0.75 | 1.50 |
| Duration %age in emergency | 12.3% | 10.9% | 6.4% | 6.7% |
| Duration %age in alert | 55.7% | 31.7% | 49.1% | 46.3% |
| Incentivization failure rate | – | 1.6% | 1.2% | 1.3% |
| Incentivization (€/MWh) | – | 36.30 | 64.47 | 60.68 |
| Max. Net Demand (p.u.) | 1.28 | 1.30 | 1.23 | 1.25 |
| Max. Net Generation (p.u.) | 0.96 | 0.74 | 0.52 | 0.51 |
| Total Consumption (MWh) | 37.42 | 37.39 | 37.31 | 37.03 |

simulated. In the base case, business as usual is taken under consideration. In the second case, the congestion management is performed without user-centric data-driven modelling. In the third and fourth case, the congestion management is performed with user-centric data-driven modelling but without and with pre-data initialization.

The outcomes, as shown in Table II, was obtained by simulating for ten days, during which the agents interacted with eachother for the process of pre-exploration. Moreover, the granularity of time interval for simulation is set to 15 min(meaning 96 intervals per day).

Case 3 and 4 realizes a significant reduction in the duration of the congestion with a slight drop in the total energy consumption. The experiment is simulated in the real-time environment, so it can be presumed that the part of the dispatchable load is still available for future demand dispatch. On the other hand, the allocation of flexible demand results in a high consumption peak in case of incentivization without any learning.

Moreover, case 3 reduces the congestion duration almost 80% and 67% concerning case 1 and 2, respectively. It is also evident that in both case 3 and 4, the maximum loading is lower than 1.25p.u. (i.e., 500kVA) and the maximum generation is around 0.5p.u. It is because DSO agent tries to utilize most of the flexibility to mitigate the congestion, thus results in reducing available demand flexibility for future use.

Moreover, the host network experiences the alert situation around 15% more than case 2. Although peak load, as well as the congestion duration, are largely reduced in both case 3 and 4, the rebound effect of the demand results in an alert situation. However, the percentages when the network experiences the alert situation in all cases are still found lower than the base case.

## V. CONCLUSION

Since being agile is different from being flexible, so the study related to agile development process in energy system is in the early stages, and further understanding and research is required. Therefore, this paper provided further understanding and research for the agile development process as a user-centric data-driven methodology implemented via multi-agent technology. It addresses how need-owner can achieve its business objectives with a clarity of purpose, focus, and goals.

Later, the paper presented a agile methodology that helps need-owners to co-create the technical solutions that could be implemented in their energy systems to meet their business needs. Moreover, the methodology enables the identification of agents that would be added to multi-layer agent architecture as processing steps towards the agile development. Thus the architecture and mechanisms proposed herein is referred to as the agile methodology. Within the methodology, multi-layer is enhanced by exploring hybrid structuring of multi-agents and exploits it by signifying data-driven models of the agents. Lastly, the paper identifies the development of the agile processes through object-oriented programming. In this way, the methodology can be easily integrated into toolchain of a DSO (i.e., considered as a need-owner for the explanation purposes).

In future work, the proposed methodology can be validated in large projects, where DSOs might use it to evaluate their technical solutions and to be agile in achieving their goals in future market models.

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