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Unlocking residential Energy Flexibility on a large scale through a newly standardized interface

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***Abstract*—Energy Flexibility is the ability of smart devices to deviate from their normal energy producing or consuming behaviour, while still fulfilling their intended purpose, with the goal of contributing to the operation of the energy system. Energy Flexibility has the potential to counteract the mismatch between production and consumption of energy as well as solving congestion problems in the grid therefore increasing the resilience of the energy system. There are many systems for utilizing and coordinating Energy Flexibility, varying in complexity, used incentives and technology. In this article, the Energy Flexibility Interface (EFI) is proposed. This interface, positioned between device and Energy Flexibility utilization system, provides a generic language for Energy Flexibility. The interface allows any device providing Energy Flexibility to work with any Energy Flexibility utilization system. Hence, Energy Flexibility can be utilized on a large scale while reducing implementation efforts and creating a level playing field for both devices and Energy Flexibility utilization systems. EFI is demonstrated in a dozen pilot projects and forms the basis of a European prestandard.**

***Index Terms*—Energy Flexibility, Interoperability, Standardization, Demand Response.**

I. INTRODUCTION

The way electricity is being used changes while we go through the energy transition. The intermittent production of, for example, solar panels and wind turbines makes it more difficult to match production and consumption of electricity in the power grid. This mismatch is currently limiting the amount of renewable energy that can be used [1]. In addition, new applications of electricity, such as electric heating and electric vehicles, can lead to congestion problems in the power grid. Electricity storage has the potential to solve these problems, but it is not economically viable to use this as the only solution. Luckily, some devices can deviate from their normal energy producing or consuming behaviour, while still fulfilling their intended purpose. For example, charging an electric vehicle can sometimes be postponed, or heat can temporarily be stored in a heat buffer. The ability of a smart device to deviate from its normal energy production or consumption, while still fulfilling its intended purpose, is what we call its *Energy Flexibility*. Energy Flexibility has the potential to counteract the mismatch between production and consumption, as well as solving congestion problems in the power grid, therefore increasing the resilience of the grid.

Industrial processes can produce or consume significant amounts of energy, which can make it relatively easy to implement Energy Flexibility in a profitable way. However, when we look at Energy Flexibility in the residential domain, we see that the amount of Energy Flexibility per device is relatively low, but that the potential number of devices that can provide Energy Flexibility is very high. In order to make residential Energy Flexibility viable, the costs of it per device must be reduced drastically.

On the other side there are many methods for utilizing Energy Flexibility, varying in complexity, used incentives and technology. Currently used incentives are usually in the form of tariff schemes, such as feed-in tariffs and distribution grid tariffs based on the power capacity of the grid connection. Automated systems can save the consumer money by utilizing the Energy Flexibility of devices. More complex tariff schemes are proposed and implemented, such as hourly tariffs and real-time pricing. Many advanced systems are proposed, such as Demand Response or Demand Side Management [2] and Transactive Energy [3]. In addition, Aggregators operate (proprietary) control systems for using aggregated Energy Flexibility to maximize profits on wholesale energy markets or balancing markets. Since every approach optimizes towards a specific use case, it is to be expected that many technologies will continue to coexist. Moreover, since technologies evolve and the energy transition moves on, it is likely that the implemented technologies, and thus also the optimization algorithms for Energy Flexibility, will change over time. These changes will probably happen throughout the lifetime of devices, and without a well defined Energy Flexibility interface, we must rely on firmware or hardware updates from device manufacturers to support new technologies.

Since there are many types of devices providing Energy Flexibility, as well as many system for utilizing Energy Flexibility, there is a practical problem: each Energy Flexibility utilization system needs to implement an interface towards every type of device that provides Energy Flexibility. Implementing a custom interface for each device for each Energy Flexibility utilization system would require a huge implementation effort, it will promote a lock-in between devices and the Energy Flexibility utilization systems and therefore will significantly hinder large scale rollout.

In this article the *Energy Flexibility Interface* (EFI) is proposed. This interface communicates the Energy Flexibility of a device, instead of device specific parameters. This way,

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it is possible to create a generic interface, which allows every device providing Energy Flexibility to work with any Energy Flexibility utilization system. Moreover implementation and maintenance costs can be reduced, a level playing field for both devices as Energy Flexibility utilization systems is created and lock-in is prevented. EFI is demonstrated in many pilot projects and is currently input for European standardization.

II. ENERGY FLEXIBILITY PATTERNS

There are many types of devices and processes that have the potential to provide Energy Flexibility. Following a bottom-up approach we identified several basic patterns of flexibility which can also be combined into more complex patterns.

Although most uses cases revolve around electricity, these flexibility patters also apply to other types of energy, such as natural gas or heat. The basic patterns are described below.

1) *Limit production or consumption:* Some devices produce or consume energy that in principle is not controllable, but can be limited if necessary. Typical examples are solar panels and wind turbines, which only produce energy when there is solar irradiation or wind available respectively, but they can be limited in production, which is typically referred to as *curtailment*.
2) *Shift production or consumption in time:* Another flexibility pattern is the ability to shift an entire production or consumption pattern over time. A good example of a device that offers this flexibility pattern is a washing machine with a delayed start option.
3) *Pause a task:* A device might be able to pause while performing a task. For example, some washing machines have the possibility to pause between parts of the program, e.g. between the heating and washing cycle. Some devices can pause at arbitrary points, others can only pause at predetermined points in the program. Usually there is maximum pause time, or a deadline for completing the task.
4) *Alternative energy profiles:* This pattern offers multiple options to perform a certain task, while using the same energy type. Dish washers, for example, have the ability to heat the water quickly with a lot of power, or slowly with less power. The resulting energy profiles for both options are different, however in both cases the water will be sufficiently heated.
5) *Power modulation:* This pattern describes devices that are able to modulate their energy production or consumption, without any consequences for the flexibility of the device. Typically the purpose of these devices is to balance a micro grids. A diesel generator is a good example as it can produce power at will. Another example is *flaring*: disposing of excess energy, typically in the form of heat.
6) *Buffer energy:* Some devices are able to buffer energy in some way. There is a component that puts energy in the buffer and converts it into another form, while another component can retrieve the (converted) energy from the buffer. A good example would be an electrical water boiler for providing hot tap water.
7) *Store energy:* When energy is buffered, it is not possible to transform the buffered energy back to the original form or energy, e.g. hot water cannot be converted back into electricity. In the storage pattern energy can be retrieved in the same form as it was put in. A typical example is a battery storage, where electricity can be stored in the battery, and at a later moment in time be retrieved.
8) *Switch energy type:* The last flexibility pattern is the ability of a device to choose between different forms or energy to reach the same objective. For example, a heat pump can be complemented by a gas boiler.

Note that the above Energy Flexibility patterns do not always occur in isolation. In order to understand how a device behaves we typically need to combine several patterns into a more complex one (see Section III-C). Take a battery for example, it combines the *Power modulation* and *Store energy* patterns.

III. THE ENERGY FLEXIBILITY INTERFACE (EFI)

Automated utilization of Energy Flexibility needs to be facilitated by the device. There are many ways to utilize Energy flexibility, and there are many types of devices, from different manufacturers, with different purposes, which can expose Energy Flexibility. In order for every device to work with every system, each Energy Flexibility utilization system must support all devices, and each device must support all Energy Flexibility utilization systems. This is obviously not feasible.

However, we have observed, see Section II above, that there is a limited number of basic Energy Flexibility patterns. This creates an opportunity: we propose to introduce an intermediate protocol between the device and the Energy Flexibility utilization system. Here we make the distinction between *what* Energy Flexibility a device exposes, and *how* this Energy Flexibility must be utilized. This way, interoperability is created between the two systems: every device can work with every Energy Flexibility utilization system, without the need of developing any additional software. We have named this protocol the Energy Flexibility Interface (EFI).

A. Objective of the Energy Flexibility Interface (EFI)

The objective of EFI is to make every device providing Energy Flexibility to work with every Energy Flexibility utilization system. By doing this, we aim to create a level playing field for both device manufacturers and companies providing Energy Flexibility utilization services, as well as accelerating the development and adoption of new technology and businesses by removing technical barriers. EFI tries to make the least amount of assumptions on where Energy Flexibility is coming from, and what it is being used for.

When designing an interface such as EFI, there is a delicate balance between expressiveness and simplicity. Adding a lot of detail and complexity could increase the value of the

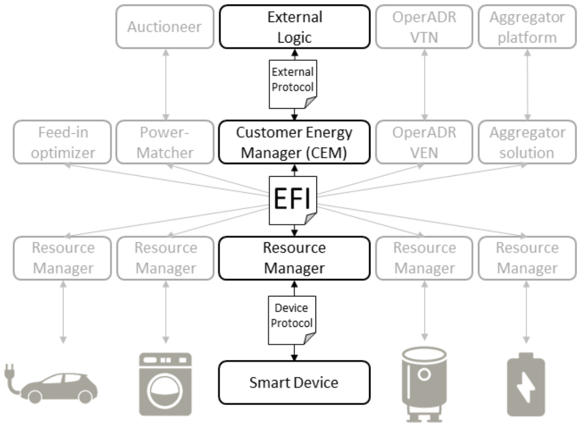

Fig. 1. Setup of the EFI architecture. Examples show how the EFI interface lets every device providing Energy Flexibility to work with every Energy Flexibility utilization system.

Energy Flexibility, while making it too simple might make some use cases impossible. Since the goal was to promote interoperability and adoption, the interface was designed to be powerful, but relatively simple, which makes it easier to implement. However, as a consequence, for the utilization of Energy Flexibility of a large (industrial) units, EFI might be too simplistic and might decrease the value of the Energy Flexibility. In such cases, a custom protocol might perform better.

It is important to realize that a device is not controlled through EFI, but rather requested to perform actions. It is the responsibility of the manufacturer to make sure that devices operate in a safe and durable manner. Whenever a device reaches for example a critical temperature, the device can reject commands it received through EFI.

EFI also has a mode for grid emergencies. When this mode is activated, instructions should be handled with a higher priority, and user comfort is allowed to be sacrificed.

EFI was designed as a *plug and play* software interface. This means that no additional configuration is necessary when a Resource Manager is connected to an Energy Flexibility utilization system. The system must receive all the information relevant for energy management through EFI.

B. EFI Architecture

The EFI architecture has the following components and interfaces, see Figure 1:

1) Smart Device: Smart devices can perform a wide range of functions for a consumer, e.g. white goods, solar panels, heating systems or EV's. Although these devices can be very different in nature they do have one thing in common; their ability to provide Energy Flexibility.

2) Device Protocol (optional): A smart device has the ability to communicate information about its state and may also be able to receive instructions. There is a huge variety of protocols. Protocols can be device specific, or can already have standardized data models for certain types of devices. Examples of standardized protocols are ZigBee, Modbus and Bluetooth. These protocols are typically not designed for energy management in particular, but can also facilitate for example home automation or remote maintenance.

3) Resource Manager: The Resource Manager is a software component that translates (detailed) device information into the more abstract Energy Flexibility concepts in EFI. It typically represents a single device, but it can also represent a group of devices which are cooperation, such as a heating, ventilation and cooling system. Translating information into EFI is typically not a straightforward mapping. The CEM typically filters out information that is not relevant for Energy Flexibility, but also needs to add knowledge about the device. For example, the Resource Manager might need to learn the capacity of a thermal buffer. A Resource Manager can be implemented on the device itself, in which case the Device Protocol can be omitted.

4) EFI: The objective of EFI is to describe the Energy Flexibility information and instructions in device and optimization goal agnostic manner.

5) CEM: The *Customer Energy Manager* (CEM) is a software component that receives the Energy Flexibility information via EFI messages from the Resource Managers. A CEM typically manages the Energy Flexibility of all devices in on the premise. It is the job of the CEM to decide how to optimize the use of the flexibility that the Resource Managers provided. In addition to EFI connections, the CEM could also receive information from other sources to perform its task, such as the weather information or (smart) meter information.

6) External Protocol (optional): Although for some applications the CEM does not require external communication (e.g. when optimizing for a feed-in tariff), most CEM implementations do require some external input. This input can take on many different forms, such as incentives (e.g. tariff information), a more direct instruction (e.g. an OpenADR load shedding message), or more advanced mechanism (e.g. Transactive Energy or optimization by an Aggregator). The design of such a protocol highly depends on the optimization goal of the system, so EFI tries not to make any assumptions on the working of the external protocol.

7) External Logic (optional): This component is trying to optimize over multiple CEM's and is typically run by a party that is interested in the (commercial) utilization of Energy Flexibility. This party should be free to implement its very own business model and technology stack, therefore EFI can not make any assumptions about the implementation of this component.

It is important to emphasize that the CEM and the Resource Manager are logical concepts and that we do not make any implications on where they should be deployed. The Resource Manager, for example, might be implemented on the device itself, on a gateway that also runs the CEM or in the cloud.

C. Practical Use of EFI

EFI realizes its objective by focusing on Energy Flexibility concepts. The basis for this is formed by the Energy Flexibility patterns described in Section II. In order to work practically with EFI, these patterns have been clustered into four flexibility categories, named Inflexible, Shiftable, Adjustable and Storage. A device providing Energy Flexibility can be mapped onto one of these four categories. Each category has its own distinct set of data models, messages and sequences. The clustering is the result of multiple iterations, where experience from pilot projects was incorporated (see Section IV). In these pilot projects a wide range of devices and control algorithms were implemented. The aim of the four categories is to pragmatically combine the basic flexibility patterns and to describe interdependencies between them.

1) Inflexible: Inflexible devices, in principal, do not provide any option to control their flexibility. However there are devices that offer a curtailment option that may limit the power production or consumption (Energy Flexibility pattern 1, as mentioned in Section II). There are a lot of devices which do not provide any Energy Flexibility, such as TV sets and water cookers. A typical example of a device that may offer curtailment is a solar panel. The curtailment option may be called upon when solar production reaches a peak that can not be accommodated by the local grid (typically referred to as peak shaving). Although this category of devices does not offer any flexibility other than curtailment, the behaviour of these devices can still be very relevant to the CEM. There are two options within EFI for an inflexible device to inform a CEM about its behaviour: power measurements and power forecasts.

2) Shiftable: Shiftable devices perform a task that has a corresponding power profile that is known or predicted on forehand. Their flexibility mainly comes from the ability to change the start time of that power profile, or choose between alternatives. Devices with a delayed start option, such as dishwashers, are good examples of this category. A consumer fills up the dishwashers with dirty dishes, selects a program and chooses the final time by which this program should be ready. The CEM can then decide what the best possible start time is, given its optimization objectives. This category combines the Energy Flexibility patterns 2, 3, 4 and 8 as mentioned in Section II.

3) Adjustable: Devices in the Adjustable category have the possibility to control the amount of power they produce or consume, without significant effects on the Energy Flexibility in the future (Energy Flexibility pattern 5 and 8, as mentioned in Section II). Devices in the Adjustable category are often useful for balancing microgrids. Typical examples of the Adjustable category are diesel generators and variable electrical resistors. Adjustable devices offer a lot of flexibility; they can assume a range of power levels at almost arbitrary moments in time. It is practical to model the Adjustable category as a state machine. A device can declare multiple *running modes*. A running mode is a mode in which a device can be, and has a particular energy production or consumption associated with it. With the information a CEM receives through the Adjustable EFI category, it is able to determine exactly what it can expect from a device. This way, a CEM can know what its options are given the current situations, but it is also able to create a realistic plan for the future. Using the state machine and all associated constraints, all the possibilities of the device are known beforehand. A CEM can instruct an Adjustable device by sending the desired state and the time the state transition should take place.

4) Storage: The Storage category can be used for devices that can store or buffer energy (Energy Flexibility pattern 6, 7 and 8, as mentioned in Section II). How energy is stored or buffered does not matter, as long as there is a means to measure how *full* the storage or buffer is. There are many examples of devices that can store or buffer energy, such as heating systems, stationary batteries and electric vehicles. The main component of the EFI Storage category is the storage itself. A device must be able to inform the CEM about its *fill level*, a measure of how full the storage is, and the acceptable boundaries of the fill level. With the information the CEM receives about the Storage device, it is able to determine the current and future possibilities. The CEM can send instructions to the device by sending the desired running mode for a certain actuator and the desired time of the transition.

In addition to the before mentioned functionality, devices from any of the four categories can provide the CEM with power measurements.

IV. EFI IMPLEMENTATIONS

EFI is the result of experience and knowledge gained in many pilot projects. In pilot projects the technology is deployed in real world scenario's, where it has to be part of a functioning ecosystem of technologies, often with real users. EFI was redesigned several times based on insights gained in pilot projects. Some notable examples of CEM implementations are based on PowerMatcher [4], HeatMatcher [5], Triana [6] and OpenADR [7], as well as many custom, pilot specific energy management algorithms.

In one of the pilots called Energy Front Runners [8] in the Dutch city of Heerhugowaard, EFI has been used to control curtailable solar panels, heatpumps, electric water boilers, stationary batteries and fuel cells in 200 participating households. In this project, the DSO procures congestion management services through a USEF [9] market from a commercial independent Aggregator. The Aggregator financially compensates the device owners for the provided Energy Flexibility. In this project the PowerMatcher algorithm was used to control the devices.

Another notable project where EFI is used is the Dutch pilot of the Interflex European Horizon 2020 project [10]. In this project, the flexible devices are managed and serviced by an independent company through a *Local Infrastructure Management System*. This system implements EFI and makes the Energy Flexibility available for two commercial Aggregators, each with their own technology stack. Energy Flexibility is used for both optimization for energy wholesale markets, as well as providing congestion management services for the DSO.

Finally, a notable example of a pilot project is HeatMatcher, which has been used at several test sites in The Netherlands.

The HeatMatcher algorithm does not only try to optimize electrical Energy Flexibility, but also heat and natural gas usage, proving that EFI can also be used for these commodities. The result of HeatMatcher is a more efficient system for heating and cooling large buildings using a combination of heatpumps, gas heaters and solar collectors, lowering overall energy costs.

V. ADOPTION AND STANDARDIZATION OF EFI

A common language for Energy Flexibility such as EFI only has value when it is used by others. It behaves like a two-sided platform business model: EFI only has added value for the developers of Energy Flexibility utilization systems when there are devices on the market that support EFI, and it only has added value for manufacturers to implement EFI in their devices when there are products or services available which use EFI to utilize the Energy Flexiblity provided by the device. This makes it relatively hard to get a concept like EFI being adopted.

EFI is governed and promoted by the *FlexiblePower Alliance Network* (FAN) [11], an organization consisting of Dutch DSO's, companies in the energy sector and the Dutch research institute TNO. One of the activities of FAN is to help the formal standardization of EFI. A standardized protocol can benefit adoption by manufacturers and creates the possibility to refer to the standard in legislation and regulation. The EFI architecture is standardized in EN50491-12-1 of the European Committee for Electrotechnical Standardization (CENELEC), while the prEN50491-12-2 prestandard contains the Energy Flexibility data models based on EFI. The ambition is to create an international standard through the International Electrotechnical Commission (IEC). FAN also provides an open source reference implementation of a behind-the-meter energy management software platform which implements the architecture in Figure 1. This platform is named EF-Pi [12].

VI. CONCLUSION

The availability of Energy Flexibility on a large scale has major advantages. It can be used to provide congestion management services, which can postpone or avoid grid reinforcements. Also, Energy Flexibility can help to balance the grid by matching energy supply and demand, thus increasing the carrying capacity of the grid for renewable energy sources. Energy Flexibility from residential devices is still a largely untapped source. Due to the great variety of devices and systems for utilizing the Energy Flexibility, it is difficult to unlock flexibility on a large scale.

This article proposes the Energy Flexibility Interface (EFI); an interface between Energy Flexibility utilization systems and smart devices. Since devices always follow a limited number of basic Energy Flexibility patterns, it is possible to design a relatively simple and compact interface which can support all types of residential Energy Flexibility. EFI only communicates how the device can behave from an energy point of view without the need to expose the inner workings of the device. This way, interoperability between device and Energy Flexibility utilization systems can be achieved. Through interoperability Energy Flexibility can be utilized in a cost-effective manner, lock-in can be prevented and it is ensured that the Energy Flexibility of existing devices can also be used by future utilization systems.

EFI has been technically demonstrated in a dozen projects. However, without the widespread adoption of such an interface it is not possible to capitalize on its potential. An important prerequisite for achieving this is standardization. That is why we have put a lot of effort into making EFI the basis of European (pre)standards, and why we have the ambition to make them into international standards. With the right standards in place, the next step is to promote adoption by device manufacturers. When these standards have been implemented in consumer devices, residential Energy Flexibility will have been unlocked on a large scale.

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