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INTERNATIONAL STANDARD

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Information technology – Home Electronic System (HES) application model – Part 3-51: Framework of a narrow AI engine for a premises energy management system using energy management agents

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INFORMATION TECHNOLOGY – HOME ELECTRONIC SYSTEM (HES) APPLICATION MODEL –

Part 3-51: Framework of a narrow AI engine for a premises energy management system using energy management agents

FOREWORD

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The text of this International Standard is based on the following documents:

Draft	Report on voting
JTC1-SC25/3225/FDIS	JTC1-SC25/3245/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1, and the ISO/IEC Directives, JTC 1 Supplement available at www.iec.ch/members_experts/refdocs and www.iso.org/directives.

A list of all parts of the ISO/IEC 15067 series, published under the general title *Information technology – Home Electronic System (HES) application model*, can be found on the IEC and ISO websites.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This document adds artificial intelligence (AI) functions to support the energy management agent (EMA) specified in ISO/IEC 15067-3 for EMAs located on customer premises. A narrow AI engine framework and guidelines for implementation in an EMA are provided. Furthermore, the placement of AI support infrastructure in an EMA addresses the challenges of developing a scalable energy management solution for home energy management. The narrow AI engine is a system that is deployed inside a home to operate as the protected on-premises system for energy management. The narrow AI engine responds to energy management events by operating an AI algorithm customized for energy management.

The HES gateway, specified in the ISO/IEC 15045 series and ISO/IEC 18012 series, supports the AI functionality. The term "premises energy management agent (PEMA)" is introduced as a type of EMA that is hosted on the HES gateway. The PEMA primarily focuses on the needs, including generation and storage, of the premises, while the connection to the public utility can also be included when aligned with the needs of the premises.

The objective of the AI functions in an EMA is to help the consumer decide from which source and when to acquire power and to which loads and at which times this power should be allocated. Sources may include a public power utility, an aggregator, a prosumer (a producer and consumer with excess power who offers the surplus for sale through a transactive energy scheme), local generators (such as wind or solar), or batteries (stationary or mobile). Loads can include consumer electronics, appliances, and EV chargers. The EMA decision assistance is predicated on the consumer's time and day preferences for appliance usage and electric vehicle (EV) charging, constrained by the consumer's budget for energy and any preference for reducing greenhouse gas emissions to mitigate climate change. The EMA is introduced to provide energy management focused on the needs of a premises, while considering local power generation such as wind turbines and solar panels, and energy storage (collectively called PER – premises energy resources).

This document specifies a high-level framework of a narrow AI engine to facilitate an energy management system. The narrow AI engine provides several capabilities such as demand prediction, decision making for energy consumption, and control. This AI framework offers a robust and scalable energy management solution for home energy management.

The EMA provides automation to help the user make and execute complex decisions in real time. We are seeking practical AI that can be deployed locally. On-premises deployment implies that the narrow AI engine can be executed in consumer or commercial electronic devices that are affordable in a competitive marketplace. Also, customer data are not shared with a service provider in the cloud, thus protecting privacy. Energy consumption patterns can reveal considerable information about equipment owned and activities identifiable by location and time. For this reason, the AI implementation specified is called "protected on-premises." In many cases, AI performance, and hence the value of the EMA, may be significantly increased if at least part of the AI learning phase is performed in the cloud or at other computational entities outside the premises. The cloud, as well as the use of additional local computational resources outside the premises, allows for use of more computational power as well as access to additional aggregated data that can improve the results of AI algorithms. If there is use of any customer data outside the premises in a learning phase, it would be subject to customer permission and may be protected by the HES gateway functions.

This AI framework may be extended beyond energy management for other home applications.

Figure 1 shows the core interoperability and HES gateway documents. Figure 2 shows the narrow AI engine series of documents consisting of three parts:

– ISO/IEC 15067-3-51: Framework
– future planned parts on data model (ISO/IEC 15067-3-52) and service procedure and message flow (ISO/IEC 15067-3-53).

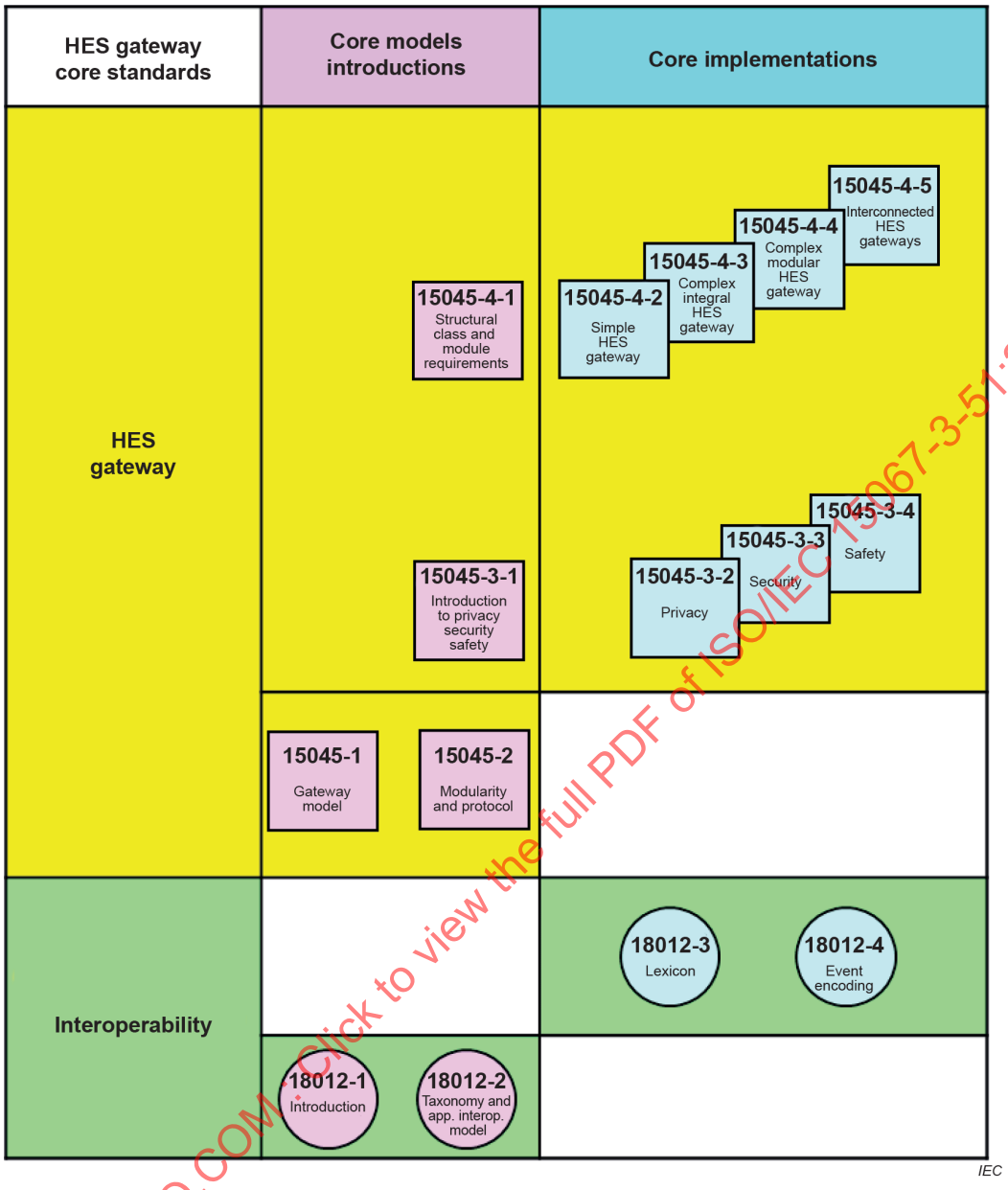

Figure 1 – Core interoperability and HES gateway

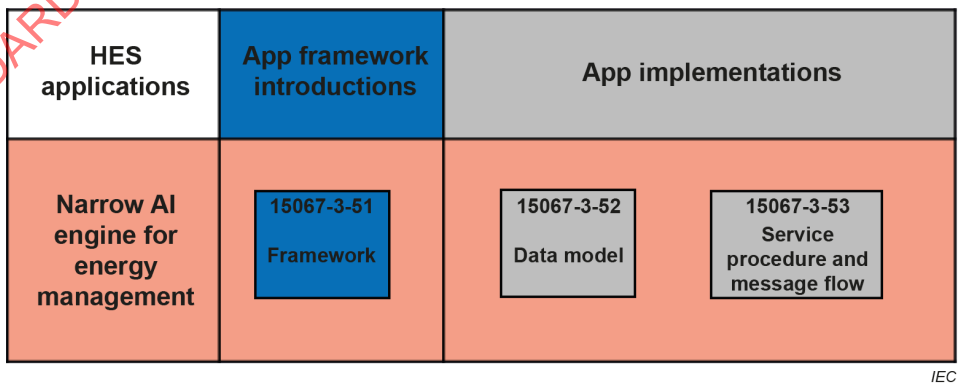

Figure 2 – HES AI applications

NOTE Additional documents needed for implementation are under development.

INFORMATION TECHNOLOGY – HOME ELECTRONIC SYSTEM (HES) APPLICATION MODEL –

Part 3-51: Framework of a narrow AI engine for a premises energy management system using energy management agents

1 Scope

This document specifies a framework for adding artificial intelligence (AI) functions to support the energy management agent (EMA) specified in ISO/IEC 15067-3 for EMAs located on customer premises. It also defines "premises EMA" (PEMA), a type of EMA that resides in the HES gateway (specified in the ISO/IEC 15045 series and ISO/IEC 18012 series).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 15045-1, *Information technology – Home Electronic System (HES) gateway – Part 1: A residential gateway model for HES*

ISO/IEC 15045-2, *Information technology – Home Electronic System (HES) gateway – Part 2: Modularity and protocol*

ISO/IEC 15067-3, *Information technology – Home Electronic System (HES) application model – Part 3: Model of a demand-response energy management system for HES*

ISO/IEC 18012-1, *Information technology – Home Electronic System – Guidelines for product interoperability – Part 1: Introduction*

ISO/IEC 18012-2, *Information technology – Home Electronic System (HES) – Guidelines for product interoperability – Part 2: Taxonomy and application interoperability model*

3 Terms, definitions, and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1.1
agent
application process in a station which accesses the locally managed objects on behalf of the manager

[SOURCE: IEC 61375-2-1:2012, 3.1.2]

3.1.2
artificial intelligence
AI
capability of an engineering system to acquire, process and apply knowledge and skills

[SOURCE: ISO/IEC 29119-11:2020, 3.1.13]

3.1.3
demand response
DR
method for matching the demand for energy to the available supply of energy

[SOURCE: ISO/IEC 15067-3:2012, 3.1.3]

3.1.4
distributed demand response
distributed DR
method for providing incentives for customers to match the demand for energy to the available supply of energy such as price and event notices rather than control signals

3.1.5
electrical energy measuring system
EEMS
automatic meter reading (AMR), advanced metering infrastructure (AMI) and measurements of energy consumption by appliances, chargers, inverters, and other devices in a premises

3.1.6
energy management agent
EMA
set of control functions that manage energy use, generation and storage as an agent for the customer

3.1.7
home area network
HAN
network serving nodes, devices, components and functions within a premises

Note 1 to entry: For an HES gateway system, a HAN is a network within the protected area.

[SOURCE: ISO/IEC 15045-2:2012, 3.1.7, modified – In the definition, "network specifically serving" has been replaced with "electronic network serving" and "home or premises" has been replaced with "premises". Note 1 to entry has been added.]

3.1.8
home electronic system
HES
collection of devices and components operating within the premises and interconnected over one or more networks in conformance with HES-related ISO/IEC standards

Note 1 to entry: The referenced ISO/IEC standards normally include HES in the title of each standard.

3.1.9
HES gateway
electronic device that transfers messages among WANs and HANs providing interoperability, privacy, security and safety according to the requirements of the ISO/IEC 15045 series and ISO/IEC 18012 series

Note 1 to entry: For an HES gateway, a WAN is a network outside the protected area and a HAN is a network inside the protected area.

3.1.10
interface
shared boundary in computing across which two or more separate components of a computer system exchange information

3.1.11
interface, service, and event encoding group
ISEE group
group of interface modules, service modules and HES-CLME event encoding to support a particular application or operation

3.1.12
machine learning
process by which a functional unit improves its performance by acquiring new knowledge or skills, or by reorganizing existing knowledge or skills

[SOURCE: ISO/IEC 2382:2015, 2123789]

3.1.13
narrow artificial intelligence engine
narrow AI engine
module that performs decision making specified to handle a singular or limited task by performing artificial intelligent computing

Note 1 to entry: Decision making includes data collecting, autonomous demand response management, recommendation to the users, etc.

3.1.14
premises energy management agent
PEMA
EMA implemented on premises inside an HES gateway to focus on the needs, including generation and storage, of the premises rather than those of a public utility

Note 1 to entry: The term "premises energy management agent" (PEMA) is introduced to specify a type of EMA that is in the HES gateway and relies on gateway services, and to clarify that it is primarily focused on the needs of the premises, while the needs of a public utility could be secondarily incorporated when they align with the needs of the premises.

3.1.15
premises energy resources
PER
local power generators using local (e.g. generation) sources or local energy storage devices to supply electrical loads in residential or commercial buildings situated at the local premises

Note 1 to entry: Renewable source may include solar, wind, and energy storage.

Note 2 to entry: A residential building may include an apartment complex, an apartment building, and a home.

3.1.16
wide area network
WAN
network that connects communication devices in the environment external to the premises

Note 1 to entry: For an HES gateway system, a WAN is a network outside the protected area.

3.2 Abbreviated terms

AI	artificial intelligence
ARIMA	autoregressive integrated moving average
CLME	common language messaging exchange
DB	database
DER	distributed energy resources
DR	demand response
EEMS	electrical energy measuring system
EMA	energy management agent
ESS	energy storage system
EV	electric vehicle
HES	home electronic system
ISEE	interface (e.g. HAN and WAN interface modules), service (e.g. service modules), and event encoding (e.g. HES-CLME)
LSTM	long short-term memory
PEMA	premises energy management agent
TE	time and expense

4 Conformance

This document specifies the components that comprise the framework for a set of EMA functions to provide an infrastructure for a narrow AI engine for energy management. It also provides a framework of services provided by the HES gateway in support of the narrow AI engine. Products that claim conformance to the HES gateway shall conform to ISO/IEC 15045-1, ISO/IEC 15045-2, ISO/IEC 18012-1, ISO/IEC 18012-2, and other standards in the ISO/IEC 15045 series and ISO/IEC 18012 series as they become available.

5 Narrow AI engine for energy management

5.1 General

As specified in ISO/IEC 15067-3, the energy management agent (EMA) provides a high-level conceptual model to control the allocation of energy from public utilities, energy service providers, and local sources (such as solar, wind, and storage) to appliances and EV chargers. Energy allocation is based on energy supply information, energy needs, consumer priorities for appliance and EV operation and use of renewable energy, consumer's budget for energy expenditures, and other consumer constraints such as reducing greenhouse gas emissions to mitigate climate change.

To enable autonomous EMA functions, embedded artificial intelligence (AI) technology is used. AI may be used to acquire, process, and apply knowledge and skills for seamless energy management of local generation, energy allocation, transactive energy, energy storage, and consumption.

5.2 Narrow AI engine for energy management in smart homes

The general logical diagram of the energy management with the support from narrow AI engine is shown in Figure 3.

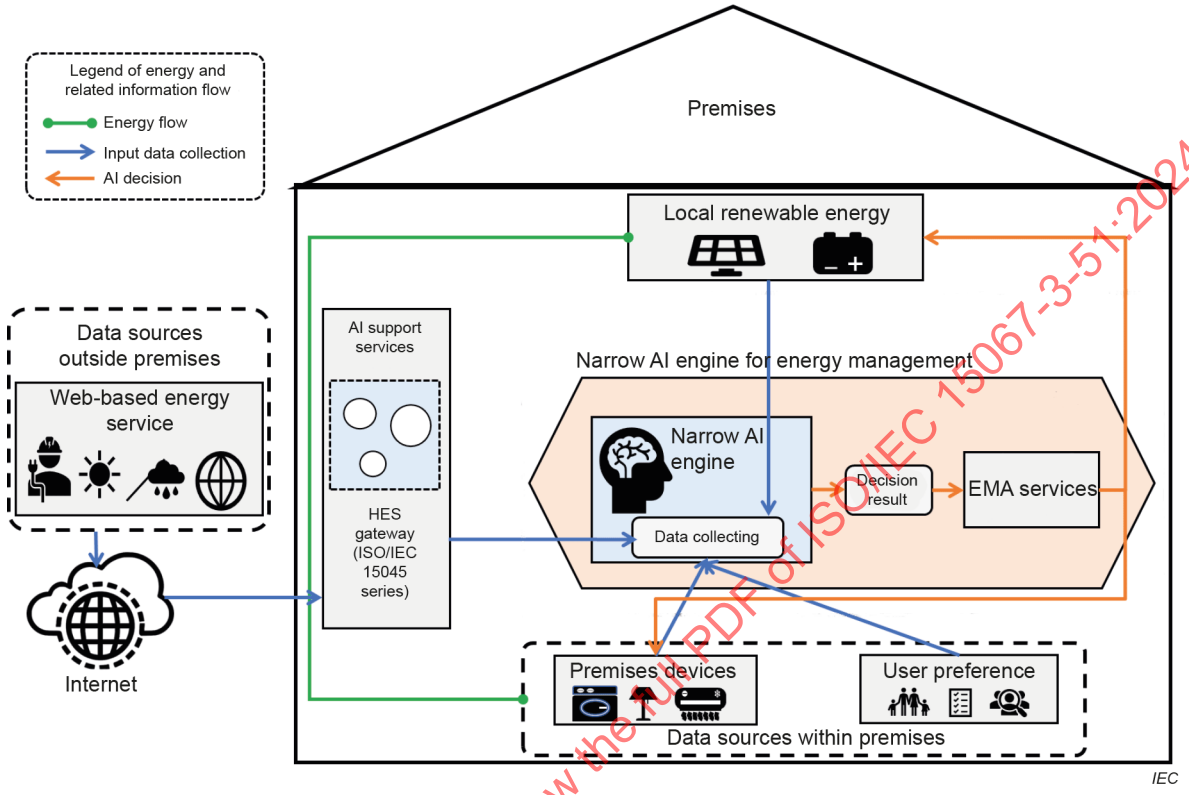

Figure 3 – Logical framework of smart home energy management with support from narrow AI engine in the deployed mode

The narrow AI engine may collect energy supply data from sources such as local renewable energy management systems and public power suppliers (such as a public utility) possibly via the Internet using a web-based energy service accessible through the HES gateway. The AI support services in Figure 3 are elements required to support the narrow AI engine. Examples of such elements are presented in Annex A. Clause 8 provides a framework of services when located in the HES gateway. In addition, device data (such as power requirements) and user preferences may be collected and protected within the home. These data are not accessible from outside the home without proper user authorization, as enforced by the HES gateway. Furthermore, data for the imported standardized ISO/IEC 18012-3 lexicon algorithms, pre-trained models, and initial parameter values may be collected by the narrow AI engine for use during the learning process, which is used to create the deployed mode of the narrow AI engine. All data transmitted into or out of the home must pass through the HES gateway, which helps to ensure privacy and security of the data. The narrow AI engine resides completely within the home, and when in the deployed mode, provides decisions for controlling power allocation by the EMA to loads in the home or building. In determining energy allocation, an EMA can process multiple factors such as energy pricing, energy load control, energy generation prediction, and energy market demand prediction. Furthermore, these factors may be inter-dependent. For example, the energy price information can optionally be used as an input to the EMA.

6 Framework of narrow AI engine for smart home energy management

6.1 General

The framework of the narrow AI engine for smart home energy management is shown in Figure 3. To make decisions about energy management on premises, data sources (inside and outside the premises) may connect with the narrow AI engine through a HAN or WAN to provide information about the following:

- functions such as web-based energy related services;
- local renewable energy;
- EMA functions;
- home devices;
- user preferences.

6.2 Entities in narrow AI engine framework

6.2.1 Narrow AI engine

The narrow AI engine enables the EMA to allocate energy to appliances and to EVs and other battery charging devices to transact energy with an external buyer or seller, to reduce energy consumption or to raise energy efficiency in a smart home, residential building, or housing community. The machine learning capability in the narrow AI engine can help the EMA to control, predict, and make decisions about maximizing efficiency in energy consumption, storage, and transmission to the grid. With the narrow AI engine, DR functions may be controlled at the EMA. Moreover, the narrow AI engine may manage the EMA to respond dynamically for effective DR management. These DR functions include interactions with local appliances, HVAC, EV chargers, etc. to implement local decisions about energy allocation, which may be based on both local and external information.

6.2.2 Electrical energy measuring system

Electrical energy measuring system (EEMS) is a general term that encompasses automatic meter reading (AMR), advanced metering infrastructure (AMI), with the addition of disaggregated measurements of energy consumption by individual appliances and EV charging stations. EEMS also includes measurements of energy flows from local power generators such as solar panels and wind turbines, and energy stored in stationary batteries or available from mobile batteries. EEMS data are important for the EMA to make allocation decisions optimally. EEMS equipment now is typically provided by the electricity supplier using an infrastructure based on centralized generation resources. As such, EEMSs today are enabled by off-premises communication systems to support electrical meters at the demarcation point. The data gathered from these utility meters are primarily for revenue and billing. However, information gathered from them may be used by the narrow AI engine in an energy management system. The information from a utility meter is collected by HES gateway.

As described in ISO/IEC 15067-3, future electricity infrastructure deployments may shift generation resources to be locally renewable and distributed. Energy demand will likely become more dynamic and integrated with supply, resulting in increased requirements for capturing and extracting the input data through EEMSs. Therefore, it will be important for the narrow AI engine to be flexible, by repeatedly reactivating its learning mode in order to derive the updates necessary for the deployed mode algorithms to accommodate these changing situations.

6.2.3 Energy management agent

The energy management agent (EMA) shall have a set of control functions that manages the energy consumption as an agent for the customer. See Clause 8, which provides more detail about service provided by the HES gateway to support the AI functions. The narrow AI engine provides energy management decisions for the EMA.

6.2.4 Local renewable energy

The local energy sources that supply renewable energy may include solar, wind, storage, etc. Data about local renewable energy such as energy generation capacity and output may be sent to the narrow AI engine. Control decisions are sent from the EMA to local renewable energy sources about when local renewable energy is to be sent to premises devices, and in some cases, when it may be sent off premises (possibly using transactive energy).

6.2.5 Premises devices

Premises devices such as appliances and EV chargers that consume significant amounts of energy may generate data for measuring and managing energy consumption. These energy data from premises devices may be sent to the EMA Data collecting service through the HAN. Control decisions are sent from the EMA to premises devices.

NOTE Example appliances include a washing machine, air conditioner, and smart lamps.

6.2.6 User preference

User preferences guide the desired configuration or timing of appliance usage to perform daily activities desired or to stay within the consumer's budget for energy expenditures. User preference data may be sent to the data collecting service of the narrow AI engine within the EMA.

6.2.7 Web-based energy related services

Web-based services or sources may provide various types of energy related information such as weather forecast, disaster alert, etc. Data related to the grid and energy markets may also be collected through the web. Pre-trained models and initial parameter values for the learning process may also be obtained through the web.

NOTE Grid and energy market data are specified in IEC 62746-10-1 and IEC TR 61850-1.

7 Narrow AI engine with EMA

7.1 General

The narrow AI engine shall have two modes: the deployed (or inference) mode and the learning mode. It is possible in some cases with adequate precautions taken, such as with reinforcement learning, for the narrow AI engine to be operating jointly and simultaneously in both the deployed and learning modes. However, in most cases the learning mode may be performed offline, separately from the operational deployed mode.

In the deployed mode, the algorithms used have already been trained and optimized by the narrow AI engine learning mode. Alternatively, the narrow AI engine "deployed mode" may use algorithms that are primarily trained and derived externally; such pre-trained algorithms may be fine-tuned with data from inside the premises in the learning mode, or else external to the premises if permission to send premises data out was granted by the premises. In the deployed mode (or "inference mode"), the narrow AI engine provides energy management decisions for the EMA to send to the attached premises appliances, DER equipment, and local renewable energy sources, as shown in Figure 5. These AI algorithms make continual decisions about energy management in the deployed mode.

Before initial operational deployment, the learning mode may be activated to configure the AI algorithms for use by the deployed mode in the initial environment. Again later, the learning mode may be reactivated, and its algorithm derivation may be re-executed when the operational environment changes (e.g. adding a new home device, changing external supply conditions, changing energy usage patterns as occupants or other conditions change, etc.). Thus the learning mode of the narrow AI engine may be activated on an as-needed basis or at regular intervals to create new or updated algorithms for use in the deployed mode; these new or updated algorithms are the output of the narrow AI engine's learning mode, as shown in Figure 6.

If the narrow AI engine learning mode is not periodically activated to update the deployed mode algorithms, then another function may be run periodically or continually to detect changes in the environment significant enough to trigger activation of the learning mode. In addition, activation of the learning mode may be triggered in some cases by human input indicating knowledge of environmental changes.

Some specific functions that may occur within the narrow AI engine in the two modes are outlined in 7.5.

7.2 Algorithm derivation

Modules that perform computational tasks in the learning mode to create deployable algorithms for the deployed mode may be considered part of algorithm derivation. These modules may train, validate, test, and optimize algorithms that are selected as potential candidates.

NOTE The procedure for managing the environmental changes that affect algorithm creation is beyond the scope of this document. Detailed data flow will be specified in a future AI related subpart in the ISO/IEC 15067-3 series.

7.3 Algorithm and decision management

In the learning mode, one or more potential candidate algorithm types may be selected for algorithm derivation. Pre-trained algorithms and initial values for model and learning parameters may also be derived externally from the premises in the learning mode and then fine-tuned as needed on premises at later stages of the learning mode.

In the deployed mode, one or more trained and optimized algorithms may be selected for execution at different instances for different functionality, including to produce decisions.

7.4 Data management

Data management modules may collect, store, and pre-process data that are acquired from within or outside the premises. Specific modules for these purposes may be deployed such as data collecting, data store, and data pre-processing. Separate data pre-processing modules may possibly handle missing data, although in some cases missing data may alternatively be handled jointly with algorithm derivation in the learning process. Different data management functions may occur in the learning and deployed modes.

7.5 Operational modes of narrow AI engine

Figure 4 illustrates the deployed mode of the narrow AI engine, where an already trained algorithm or combination of algorithms may be used for energy management decisions. In this deployed mode the narrow AI engine shall receive inputs from HES gateway, local renewable energy sources, premises devices, and user preferences, then execute energy management services (e.g. choosing power sources and power allocation to appliances and EV chargers). Use cases for an AI energy management engine can be found in Annex B.

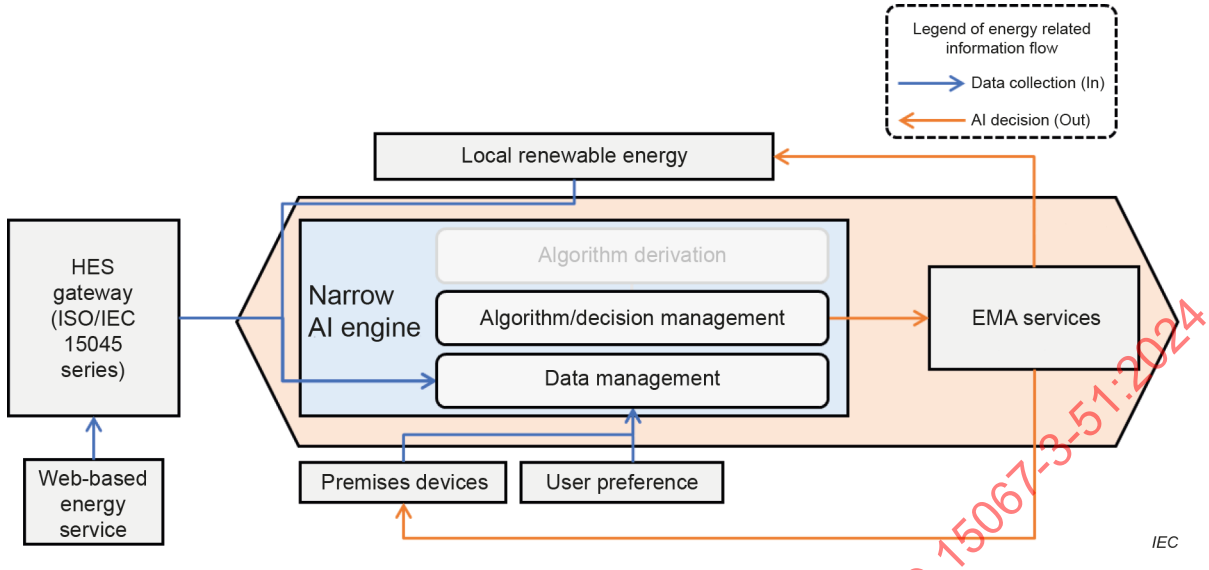

Figure 4 – Operating flow of narrow AI engine in deployed mode

Figure 5 represents the learning mode of the narrow AI engine. In this mode, a new or updated AI algorithm shall be built based on requirements for a specific energy management service for premises.

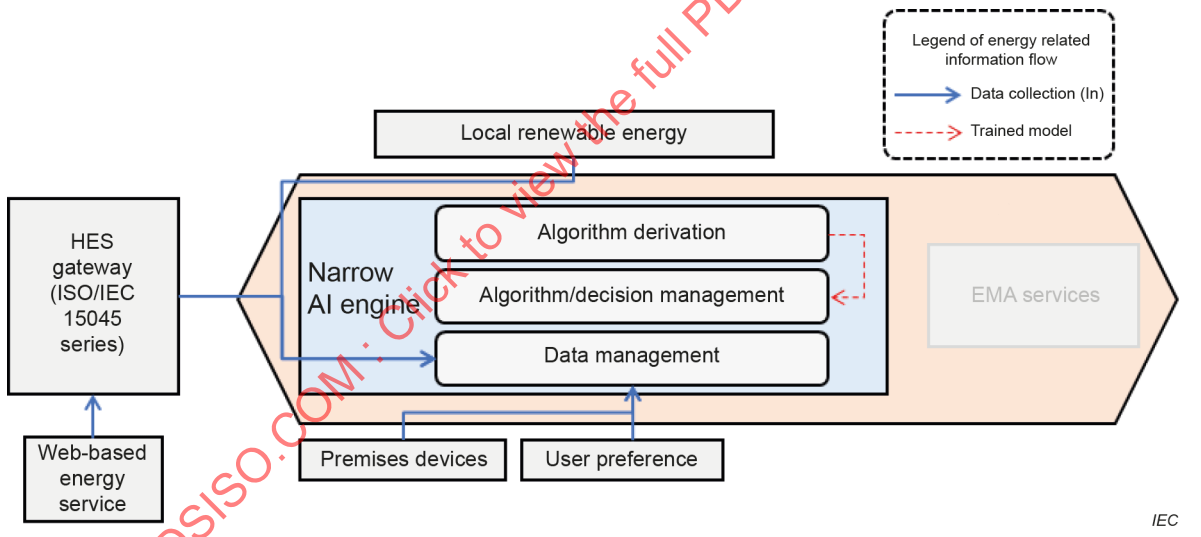

Figure 5 – Operating flow of narrow AI engine in learning mode

8 HES gateway support

8.1 HES gateway related services

An EMA may be a standalone controller, combined with other application controllers, or hosted in the HES gateway. An EMA hosted in an HES gateway is called a PEMA.

This document provides a framework for the PEMA inside of a HES gateway (as specified in the ISO/IEC 15045 series and ISO/IEC 18012 series) to support the narrow AI engine. Among these services are cybersecurity for monitoring data traffic, privacy protection of customer data, safety of device operations, HAN/HAN and HAN/WAN translation, and product interoperability.

The HES gateway provides a platform that supports the implementation of a PEMA, which would include AI services implementing the narrow AI engine as described in Annex A.

Figure 6 shows two options for energy management:

1) A PEMA hosted by the HES gateway system.
2) An EMA hosted outside the HES gateway. The narrow AI engine of an EMA outside of the HES gateway communicates with the HES gateway through a home area network (HAN), which translates AI messages into a standardized lexicon of the artificial intelligence domain as will be specified in the ISO/IEC 18012 series.

Web-based energy information and administration services that are located outside the premises are protected by the HES gateway.

8.2 Inside HES gateway

8.2.1 Framework for HES gateway services

The HES gateway provides a framework for services that are required to support an AI-based PEMA hosted on the HES gateway. These services include AI services, EEMS services and PEMA services.

These services are available for an EMA when hosted elsewhere in the premises. The location of EMA services depends on design choices made by EMA manufacturers.

The other listed services are provided for all HAN applications, as needed.

The narrow AI for PEMA application ISEE group lists the network, service modules and event encoding in the HES gateway that are required to support the functionality of the narrow AI engine. The lexicon of the objects will be specified in ISO/IEC 18012-3. Figure 6 shows the key elements of the HES gateway, including the required AI support services.

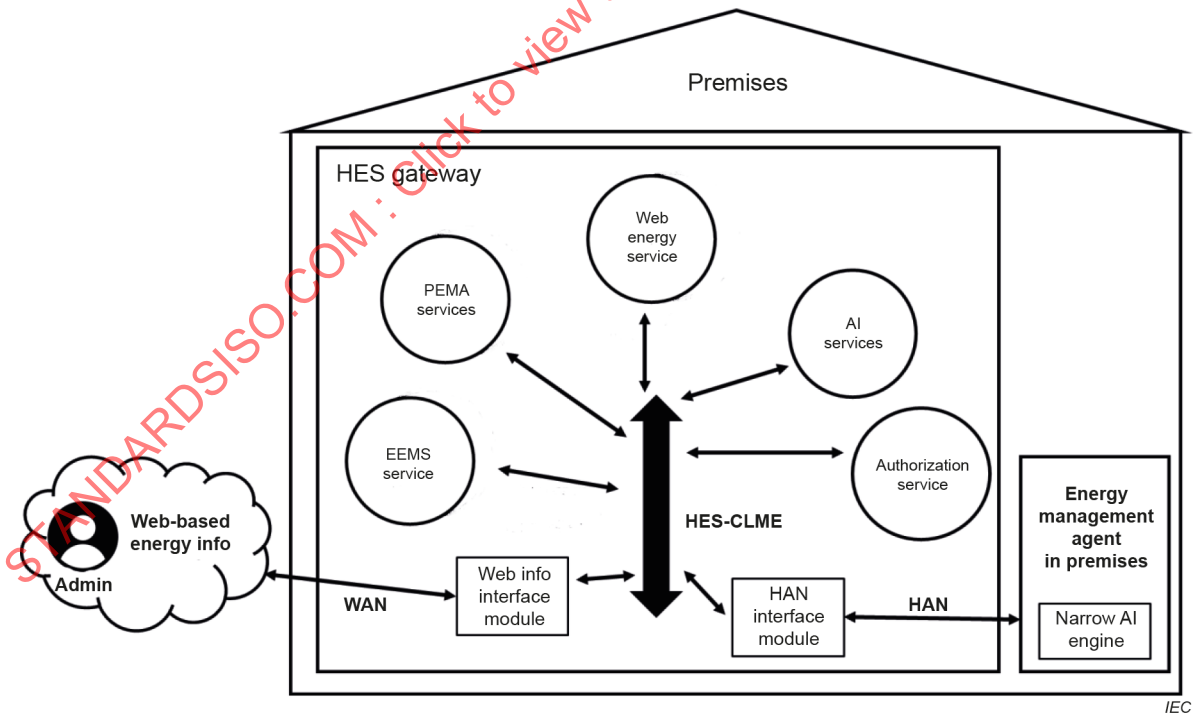

Figure 6 – Narrow AI for PEMA application ISEE group

8.2.2 EEMS service

– setup and configure the EEMS service; determines how the HES gateway handles the EEMS service

– real time processing of EEMS services

8.2.3 Web energy service

– setup and configure the web-based energy service; determines how the HES gateway handles the web-based energy information through the web WAN

– real time processing of web-based energy information through the web WAN

8.2.4 AI services

– allows the administrator to set up, configure and update standardized functions within the narrow AI engine using standardized ISO/IEC 18012-3 lexicon objects for AI

– offers to application services the ability to inquire narrow AI engines of their learning abilities and inquire and control their operational modes (e.g. deployed, learning) using standardized ISO/IEC 18012-3 lexicon objects

8.2.5 Authorization service

– authorizes services within the HES gateway, including all the services above

8.2.6 PEMA services

– supports services relating to energy management of devices including the discovery, maintenance and support of their consumption and generation capability as will be noted in ISO/IEC 18012-3

8.2.7 Web info interface module (WAN)

– interfaces to the web-based energy information service

8.2.8 HAN interface module

– interfaces to the HAN communication to the devices in the premises, which contains the narrow AI engine

8.2.9 HES-CLME

– specifies how messages related to the HES lexicon and the HES gateway are communicated

Annex A
(informative)

Example internal modules of narrow AI engine for building AI algorithm

A.1 Overview

The details of a narrow AI engine are implementation dependent. This Annex A shows an example of the internal modules of a narrow AI engine.

A.2 Internal modules of narrow AI engine

A.2.1 Block diagram of the narrow AI engine

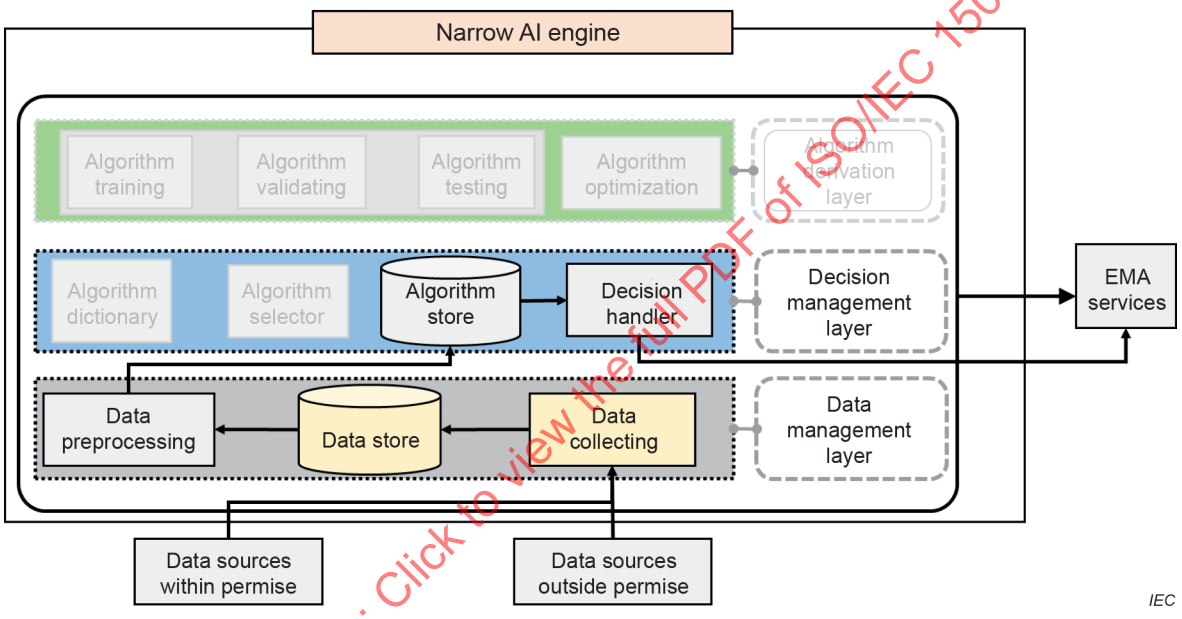

Figure A.1 – Operating modules of the narrow AI engine in deployed mode

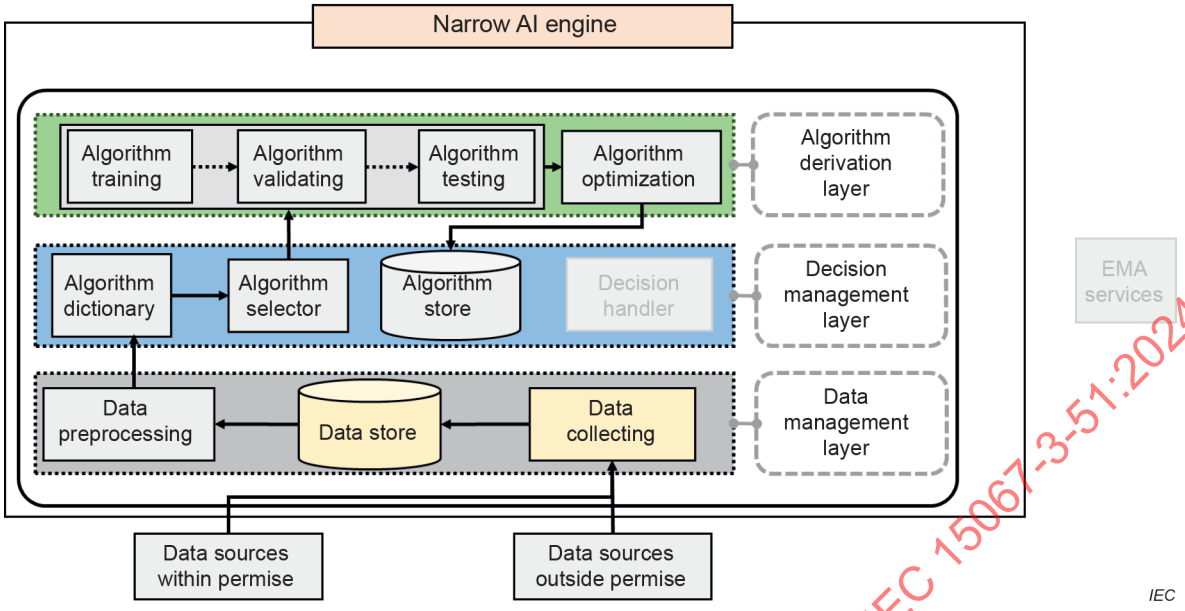

Figure A.2 – Operating modules of the narrow AI engine in learning mode

Figure A.1 and Figure A.2 show an example of operating modules for the narrow AI engine. Each layer may consist of several modules. The narrow AI engine can provide an accurate decision-making system for AI services (e.g. DR services, TE pricing, device control) in the EMA infrastructure, assuming the input data are of high enough quantity and quality. The modules of the narrow AI engine are divided into a three-layer hierarchical architecture (as shown in Figure A.1 and Figure A.2) in order to optimize a learning algorithm that provides optimal decisions for home energy management. Each module is described in detail in A.2.2 to A.2.10. A use case for home energy management (supply plan) with a narrow AI engine is presented in Clause B.1.

A.2.2 Algorithm selector

The algorithm selector module selects the suitable learning algorithm for the data and objective of the EMA from the algorithm dictionary. The algorithm selector should send policy information (i.e. metering policy, pricing policy, user preference, energy generation policy, etc.) to the algorithm training module. Additionally, a pre-trained model may be selected and stored directly into algorithm store or sent to the algorithm derivation layer for additional training for fine tuning specific to the premises.

NOTE Policies can be specified by the service provider and end user.

A.2.3 Algorithm training, validating and testing

The algorithm training, validating and testing module is activated in the learning mode to conduct the training and testing process to create algorithms that optimize the performance by minimizing training loss or maximizing the training accuracy or optimizing an alternative metric. In addition, it performs testing of the algorithm on independent datasets after training. In this module, an algorithm may be trained through pre-processed data. Validation may occur after training by using a validation dataset. After this procedure, the trained and validated AI algorithm can be tested. If the performance of an algorithm is unsatisfactory, then a new algorithm or additional data are required. Testing accuracy can also be reported as a performance metric of the narrow AI engine. The outcomes of this module may be sent to an algorithm optimization module for further model optimization.

A.2.4 Algorithm optimization

The algorithm optimization module operates in the learning mode and optimizes the trained algorithm to reduce the computation complexity as well as computational time resulting in a small variation of performance compared to the originally trained algorithm. The AI algorithm module might accommodate a trade-off between performance and complexity. To meet the computational capacity of the EMA, this module optimizes the learning algorithm by adjusting the model parameters and the structure of the learned model based on the performance of the learning algorithm. The algorithm optimization module should be capable of optimizing the trained algorithm based on the capabilities of the EMA and requirements for home energy management. This module is one of the core modules for supporting the concept of a narrow AI engine for home energy management. The optimized trained algorithm is retained within the EMA in the algorithm store. This algorithm is used in the deployed mode for decision-making about home energy management services.

A.2.5 Algorithm dictionary

The algorithm dictionary stores the generalized framework to construct the domain-specific algorithms. In this module, the various types of learning algorithms such as regression, neural networks, and tree-based algorithm should be saved to perform various types of tasks for home energy management. In addition, the algorithm dictionary module may have algorithms that are imported from outside of the premises through the data collecting module. The algorithms should be chosen based on AI services types such as transactive energy negotiation and acquisition, device control, DER management, etc. Moreover, the initial model and learning parameters that are collected by the data collecting module may be sent to the algorithm training module through the algorithm dictionary module.

NOTE The algorithms are not limited to neural networks, but can be any kind of shallow, deep, supervised, or unsupervised learning algorithm.

A.2.6 Algorithm store

The algorithm store keeps and stores the optimized algorithms, which were trained and optimized during the learning mode by the algorithm training, validating, and testing module and algorithm optimization module, respectively, for use in the deployed mode. The algorithm store may also contain algorithms for use by data pre-processing, for example algorithms for use in handling missing data. Finally, the algorithm store may contain algorithms to detect environmental changes significant enough to trigger activation of the learning mode.

A.2.7 Decision handler

The decision handler module is active in the deployed mode and manages the process of choosing and executing a suitable trained algorithm from the algorithm store for specific energy management services. This module provides an output decision based on objectives and operational data to execute home energy management services. The decision handler module processes several types of energy management services and outputs decisions about each service.

A.2.8 Data pre-processing

The data pre-processing module handles the process of creating a dataset from the raw data. Through pre-processing, it is also possible to handle missing data (although in some cases missing data may alternatively be handled jointly with algorithm derivation in the learning process). Any kind of pre-processing algorithms may be applied. One of the major roles of this module is to clean the data, and thus to increase the quality of the data. A data imputation algorithm may be applied to replace missing data in the data pre-processing module. The data pre-processing module divides the entire dataset into three groups based on the quantity of the data for training, validation, and testing datasets. The amount of data for each part depends on the various AI services of the EMA.

A.2.9 Data store

The data store keeps raw data from various data sources such as devices, an electricity meter, and web-based services. These data originate from energy generation sources and renewable sources (e.g. energy demand data, energy generation data), as well as from external data sources such as web-based services. This module may send raw data to the data pre-processing module for data pre-processing. The data store module is an option for implementation. If the narrow AI engine has no need to store the data that is collected, then the data store module should not be implemented.

A.2.10 Data collecting

The data collecting module manages the data collecting process from the various data sources such as devices, a meter, and web-based services. This module collects data such as energy consumption from home devices and stores the data in the data store. These data are considered raw data, which may be collected from appliances, meters, and any DER equipment installed in the house. In addition, the data collecting module may collect the imported algorithms, pre-trained models, and initial parameter values to assist in operating the narrow AI engine with low computational cost. The data collecting module is an independent module in the EMA that recognizes environmental changes based on the input data. This module does not interrupt the basic functionalities of the EMA.

NOTE 1 The data collection format can be any type of structured data format such as CSV, JSON, XML, etc.

NOTE 2 Algorithms, pre-trained models, and parameters can be imported from external AI system to narrow AI engine through the HES gateway.