

INTERNATIONAL STANDARD

NORME INTERNATIONALE



Industrial facility energy management system (FEMS) – Functions and information flows

Système de gestion d'énergie des installations industrielles (FEMS) – Fonctions et flux d'informations



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2023 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

Droits de reproduction réservés. Sauf indication contraire, aucune partie de cette publication ne peut être reproduite ni utilisée sous quelque forme que ce soit et par aucun procédé, électronique ou mécanique, y compris la photocopie et les microfilms, sans l'accord écrit de l'IEC ou du Comité national de l'IEC du pays du demandeur. Si vous avez des questions sur le copyright de l'IEC ou si vous désirez obtenir des droits supplémentaires sur cette publication, utilisez les coordonnées ci-après ou contactez le Comité national de l'IEC de votre pays de résidence.

IEC Secretariat
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform

The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee, ...). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished

Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

IEC Products & Services Portal - products.iec.ch

Discover our powerful search engine and read freely all the publications previews. With a subscription you will always have access to up to date content tailored to your needs.

Electropedia - www.electropedia.org

The world's leading online dictionary on electrotechnology, containing more than 22 300 terminological entries in English and French, with equivalent terms in 19 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

A propos de l'IEC

La Commission Electrotechnique Internationale (IEC) est la première organisation mondiale qui élabore et publie des Normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications IEC

Le contenu technique des publications IEC est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

Recherche de publications IEC -

webstore.iec.ch/advsearchform

La recherche avancée permet de trouver des publications IEC en utilisant différents critères (numéro de référence, texte, comité d'études, ...). Elle donne aussi des informations sur les projets et les publications remplacées ou retirées.

IEC Just Published - webstore.iec.ch/justpublished

Restez informé sur les nouvelles publications IEC. Just Published détaille les nouvelles publications parues. Disponible en ligne et une fois par mois par email.

Service Clients - webstore.iec.ch/csc

Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions contactez-nous: sales@iec.ch.

IEC Products & Services Portal - products.iec.ch

Découvrez notre puissant moteur de recherche et consultez gratuitement tous les aperçus des publications. Avec un abonnement, vous aurez toujours accès à un contenu à jour adapté à vos besoins.

Electropedia - www.electropedia.org

Le premier dictionnaire d'électrotechnologie en ligne au monde, avec plus de 22 300 articles terminologiques en anglais et en français, ainsi que les termes équivalents dans 19 langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International (IEV) en ligne.

INTERNATIONAL STANDARD

NORME INTERNATIONALE



Industrial facility energy management system (FEMS) – Functions and information flows

Système de gestion d'énergie des installations industrielles (FEMS) – Fonctions et flux d'informations

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 03.100.70

ISBN 978-2-8322-7112-4

Warning! Make sure that you obtained this publication from an authorized distributor.
Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.

CONTENTS

FOREWORD.....	6
INTRODUCTION.....	8
1 Scope.....	10
2 Normative references	10
3 Terms, definitions, and abbreviated terms	10
3.1 Terms and definitions.....	11
3.2 Abbreviated terms.....	12
4 General	13
4.1 Energy management activities in Industrial Facilities.....	13
4.2 Hierarchical structure of enterprise manufacturing system	14
4.2.1 Levels of manufacturing enterprises and the activities	14
4.3 Energy management system in a manufacturing enterprise.....	15
4.4 Role of FEMS and its expansion	16
4.4.1 Role of FEMS	16
4.4.2 Expansion of the role of FEMS	16
4.4.3 International standardization.....	17
4.5 Relation between FEMS and other systems	18
4.5.1 Relation between FEMS and other systems	18
4.5.2 FEMS and production system	18
4.5.3 Management and optimization	21
4.6 Information exchange.....	21
4.6.1 System boundary.....	21
4.6.2 Inside and outside of the facility.....	22
4.7 Data confidentiality	23
4.7.1 General	23
4.7.2 Information security	24
5 Description of functions of FEMS.....	24
5.1 Category of functions of FEMS.....	24
5.2 Monitoring Data Flows	27
5.2.1 General	27
5.2.2 Collection of actual and reference data.....	28
5.2.3 Collection of manufacturing planning information and facility status.....	29
5.3 Analysis Data Flows.....	30
5.3.1 General	30
5.3.2 Assumption for unmeasured parameters.....	31
5.3.3 Change detection in energy performance.....	32
5.3.4 Estimation of causality.....	32
5.3.5 Analysis of potential energy saving.....	33
5.4 Optimization Data Flows	34
5.4.1 General	34
5.4.2 Validation of operation strategy and constraints.....	35
5.4.3 Derivation of operation strategy	36
5.5 Instruction Data Flows	36
5.5.1 General	36
5.5.2 Report optimisation results to operator/energy manager	37
5.5.3 Output operation strategies to other systems	38

6	Classification of FEMS	38
7	FEMS Demand Response.....	43
7.1	Demand Response.....	43
7.2	FEMS and Incentive-based Demand Response.....	44
7.3	FEMS and Price-based Demand Response.....	44
Annex A	(informative) FEMS Use Cases	47
A.1	FEMS Actors.....	47
A.2	Use cases of FEMS	49
A.2.1	General	49
A.2.2	Selection of Use cases	49
A.2.3	Measurement and analysis of energy data (Visualization).....	50
A.2.4	Optimization of each unit	51
A.2.5	Optimization of each facility	53
A.2.6	Optimization of energy supply facility.....	55
A.2.7	Overall optimization	58
A.2.8	Energy Source optimization – Economics/renewables.....	60
A.2.9	Energy Profile.....	63
Annex B	(informative) Interface to exchange information for FEMS	66
B.1	Energy Storage System (ESS)	66
B.2	Peak shift.....	67
B.3	Peak shaving	68
B.4	Other Functions	69
B.4.1	General	69
B.4.2	Battery operating time forecast	69
B.4.3	Battery life monitoring.....	69
B.4.4	Function update	69
Bibliography		70
Figure 1	– Characteristic feature of HEMS, BEMS, and FEMS	13
Figure 2	– Functional hierarchy.....	14
Figure 3	– Extension to the role-based equipment hierarchy model.....	15
Figure 4	– System configuration of integration of multiple FEMS.....	16
Figure 5	– Expansion of role of FEMS	17
Figure 6	– Relationship between FEMS and other systems	18
Figure 7	– Hierarchical model of production system	20
Figure 8	– Multiple-input, Multiple-output controller	20
Figure 9	– Hierarchical structure of integrated enterprise-production system.....	22
Figure 10	– Example of Information exchange with inside and outside of the facility	23
Figure 11	– IEC 62443 Security for industrial automation and control systems standards.....	24
Figure 12	– Categories of FEMS functions and improvement cycle of energy performance	25
Figure 13	– Relationship among functions of FEMS and other systems.....	27
Figure 14	– Functions categorized under “Monitoring” and FEMS related data flow.....	28
Figure 15	– Functions categorized under “Analysis” and FEMS related data flow	31
Figure 16	– Functions categorized under “Optimization” and FEMS related data flow	35

Figure 17 – Functions categorized under “Instruction” and FEMS related data flow	37
Figure 18 – Three-dimensional map of FEMS	40
Figure 19 – General approach common today for grid management of demand response.....	44
Figure 20 – Correspondence relationship among these seven FCs and FEMS functions	45
Figure A.1 – Generic communication diagram between the smart grid and the FEMS	47
Figure A.2 – Use Case representation on three-dimensional FEMS model	49
Figure A.3 – Relationship between IEC 62264 (ISA 95) model and FEMS use-cases	50
Figure A.4 – Measurement and analysis of energy data	50
Figure A.5 – Sequence diagram of measurement and analysis of energy data	51
Figure A.6 – Optimization of each unit (inverter control of compressor).....	52
Figure A.7 – Sequence diagram of Optimization of each unit (inverter control of compressor).....	53
Figure A.8 – Optimization of each facility (quantity control of compressor).....	54
Figure A.9 – Sequence diagram of optimization of each facility (quantity control of compressor).....	55
Figure A.10 – Optimization of energy supply facility (supply-side RENKEI)	56
Figure A.11 – Sequence diagram of optimization of energy supply facility (supply-side RENKEI)	57
Figure A.12 – Overall optimization (demand and supply RENKEI).....	58
Figure A.13 – Sequence diagram of overall optimization (demand and supply RENKEI).....	59
Figure A.14 – Alternative energy sources.....	61
Figure A.15 – Sequence diagram for energy source optimization	62
Figure A.16 – Alternative energy profiles	64
Figure A.17 – Sequence diagram for energy profile optimization	65
Figure B.1 – Signal exchange diagram of the ESS and FEMS	67
Figure B.2 – Energy flow during peak shift.....	68
Figure B.3 – Peak shaving energy flow	68
Table 1 – Description for FEMS function categories	25
Table 2 – Data input and output of FEMS functions categorized into “Monitoring”	27
Table 3 – Data input and output of FEMS functions categorized into “Analysis”	30
Table 4 – Data input and output of FEMS functions categorized into “Optimization”	34
Table 5 – Data input and output of FEMS functions categorized into “Instruction”	36
Table 6 – Description of “Automation levels”	39
Table 7 – Relation between the level of automation and function	41
Table 8 – Relationship between the FCs in IEC 62872-2 [2] and the functions of FEMS.....	46
Table A.1 – Actors and roles.....	47
Table A.2 – Functions included in a Process (Measurement and analysis of energy data).....	51
Table A.3 – Functions included in a Process (optimization of each unit (inverter control of compressor)	53
Table A.4 – Functions included in a process (optimization of each facility (quantity control of compressor)	55
Table A.5 – Functions included in a process (optimization of energy supply facility (Supply-side RENKEI)) Function	57

Table A.6 – Functions included in a process (overall optimization (demand and supply RENKEI)).....	60
Table A.7 – Functions included in an energy optimization process	62
Table A.8 – Functions included in an Energy Profiles Optimization Process	65

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**INDUSTRIAL FACILITY ENERGY MANAGEMENT SYSTEM (FEMS) –
FUNCTIONS AND INFORMATION FLOWS**

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental, and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants, or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 63376 has been prepared by IEC technical committee TC 65: Industrial-process measurement, control and automation.

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

Draft	Report on voting
65/995/FDIS	65/1014/RVD

Full information on the voting for the approval of this International Standard 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 has been drafted in accordance with the ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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

The world's energy use has been increasing along with economic growth. Energy use by Organization for Economic Co-operation and Development (OECD) countries is no longer increasing. According to World Energy Outlook 2020 [3], energy demand in OECD countries has been on a declining trend since 2007 with continued increase of their gross domestic product. On the other hand, energy use in developing countries has been increasing in both growth rate and value. Energy use by the industry sector is more than 50 % of the total consumption and it is forecast to increase by about 10% between 2018 and 2030. Although the rate of increasing energy demand is lower than the rate in the report published in 2012, this increase causes serious concerns for environmental impact and presents opportunities for energy management. To control global warming, the energy from renewable resources will be increasing globally. It is expected that the share of renewable energy to total demand will increase from about 30 % in 2019 to about 40 % in 2030. Outputs of renewable energy resources such as solar photovoltaics and wind etc. require power regulation to manage integration with the overall grid. Industrial facilities are major energy consumers and, also major energy generators. Therefore, the industrial sector is expected to play a significant role to satisfy the power regulations for the smart grid using renewable energy for decarbonization. Consequently, it is quite urgent for the industrial sector to deploy energy management systems to improve the energy efficiency to support the decarbonization of society.

Energy management in the manufacturing industries is linked to production and depending on the industry it can have a very wide range of requirements. To date, energy management systems have been custom developed for/by each company and then enhanced based on practical experiences thus further customizing them. Therefore, there are many different EMS for each organization. As coordination between related organizations becomes necessary for the optimal operation of each facility, the functions of an industrial Facility Energy Management System (FEMS) are required to be standardized to realize the benefits of making better use of the available energy within and across enterprises and organizations.

Production systems have a hierarchical layered structure such as Enterprise Resource Planning (ERP), Manufacturing Operations Management (MOM) / Manufacturing Execution Systems (MES) and Control. FEMS may have been installed parallel to each layer of the production system to communicate with them. As the production system is integrated for overall optimization, expanding the boundary of FEMS for the horizontal and/or vertical integration of FEMS is also required to have an input to that integrated production system structure.

For overall optimization, the production system executes under the multiple constraints such as safety, cost, quality of products, production schedule, market requirement, energy, and others particular to the industry and application. These multiple constraints are prioritized according to the business situation and used as the objective functions for optimization. Due to the complexity and continuous variability of practical operation conditions, the objective functions for optimization, in most cases, are set to the production system manually by an experienced engineer or operator who has deep knowledge of the operation. FEMS have been supporting those people by providing necessary information for their decision-making processes during the operation.

As a FEMS needs to collect energy related information from many kinds of production systems, MOM/MES and ERP, the volume of information has been increasing extensively. It is necessary to clarify the necessary information and functions for energy management. It is also necessary to automate the execution processes of functions of FEMS including the decision-making processes for optimization as possible.

Automation technologies including modelling, simulation, Artificial Intelligence (AI), and others enable automating the process for optimization thus reducing manual operation / intervention. FEMS provide necessary functions and information for the above-mentioned optimization.

FEMS functions need to be defined as an international standard to improve interconnectivity between the FEMS and other related systems. This document proposes to define the functions, information flows and classification of FEMS based on the level of achievement of FEMS capabilities. The level of automation of FEMS functions will be one factor to define the classification. The level will provide management with a motivation and path for a stepwise progression through the classification. The resulting FEMS standard increases the sophistication of control in industrial complexes and processes so that improved optimization of facility operations can be obtained. Furthermore, the information exchange among FEMS and other systems such as MOM/MES and ERP will be defined for the integration.

International standardization will benefit both end users and suppliers of FEMS.

INDUSTRIAL FACILITY ENERGY MANAGEMENT SYSTEM (FEMS) – FUNCTIONS AND INFORMATION FLOWS

1 Scope

This International Standard specifies the functions and the information flows of industrial Facility Energy Management System (FEMS). Generic functions are defined for the FEMS, to enable upgrading traditional Energy Management System (EMS) from visualization of the status of energy consumption to automation of energy management defining a closer relation with other management and control systems. A generic method to classify the FEMS functions will be explained. The information exchange between the FEMS and other systems such as Manufacturing Operations Management (MOM), Manufacturing Execution System (MES) and Enterprise Resource Planning (ERP) will be outlined.

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.

IEC 62264 (all parts), *Enterprise-control system integration*

IEC/TS 62872-1:2019, *Industrial-process measurement, control and automation – Part 1: System interface between industrial facilities and the smart grid*

IEC/TR 62837:2013, *Energy efficiency through automation systems*

ISO 22400-1:2014, *Automation systems and integration – Key performance indicators (KPIs) for manufacturing operations management – Part 1: Overview, concepts and terminology*

ISO 22400-2:2014/AMD1:2017, *Automation systems and integration – Key performance indicators (KPIs) for manufacturing operations management – Part 2: Definitions and descriptions – Amendment 1: Key performance indicators for energy management*

3 Terms, definitions, and abbreviated terms

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

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

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

3.1 Terms and definitions

3.1.1 device

independent physical entity capable of performing one or more specified functions in a particular context and delimited by its interfaces

Note 1 to entry: A device can form part of a larger device.

[SOURCE: IEC 61804-2:2017, 3.1.18, modified – addition of note from IEC 80004-9:2017, 3.1.1]

3.1.2 equipment

component or arrangement of components, built for specific function(s)

[SOURCE: ISO 19901-5:2016 (en), 3.17, modified – deletion of: Notes 1 & 2]

3.1.3 enterprise

one or more organizations sharing a definite mission, goals and objectives which provides an output such as product or service

[SOURCE: IEC 62264-1:2013, 3.1.10]

3.1.4 facility

site, or area within a site, that includes the resources within the site or area and includes the activities associated with the use of the resources

[SOURCE: IEC 62264-1:2013, 3.1.20]

3.1.5 operator

entity responsible for the minute-by-minute execution and safe functioning of a facility

3.1.6 organization

company, corporation, firm, authority or institution, or part or combination thereof, whether incorporated or not, public, or private, that has its own functions and administration

Note 1 to entry: For organizations with more than one operating unit, a single operating unit may be defined as an organization.

[SOURCE: ISO 14001:2004, 3.16, modified – reference to enterprise removed.]

3.1.7 plant

physical unit for a comprehensive process including the dedicated functional unit(s) for control

EXAMPLE: Heating plant, ventilating plant, air conditioning plant, chiller plant, sanitary installation, or electrical installation.

Note 1 to entry: A plant can consist of several partial plants that are assembled from equipment, units, or aggregates (e.g., boiler), devices, modules, components, and elements.

[SOURCE: ISO 16484-2:2004, 3.149, modified – Note 2 deleted, addition of (s) to "unit"]

3.1.8

site

identified physical, geographical, and/or logical component grouping of a manufacturing enterprise under a single management

[SOURCE: IEC 62264-1:2013, 3.1.39, modified – addition of “under a single management” after “enterprise”]

3.1.9

unit

lowest level of equipment typically scheduled by the Level 4 or Level 3 functions for continuous manufacturing processes

3.2 Abbreviated terms

APO	Advanced Planning and Optimization
BEMS	Building Energy Management System
CMM	Capability Maturity Model
DER	Distributed Energy Resource
EMS	Energy Management System
ERP	Enterprise Resource Planning
FC	Functional Component
FDREM	Facility Demand Response Energy Management
FEMS	Facility Energy Management System
HEMS	Home Energy Management System
IP	Intellectual Property
KPI	Key Performance Indicator
LIMS	Laboratory Information Management System
MES	Manufacturing Execution System
MIMO	Multiple Input Multiple Output
MOM	Manufacturing Operations Management
MPC	Model Predictive Control
OECD	Organisation for Economic Co-operation and Development
MV	Manipulated Variable
PV	Process Variable
PCS	Process Control System
PID	Proportional Integral Derivative
SISO	Single Input Single Output
SV	Setpoint Value
WMS	Warehouse Management System

4 General

4.1 Energy management activities in Industrial Facilities

In the customer domains of energy such as Home, Building/Commercial and Industry, energy management systems: Home Energy Management System (HEMS), Building Energy Management System (BEMS) and FEMS respectively have been deployed depending on the characteristics of energy consumption. Figure 1 depicts the characteristic features of FEMS, BEMS, and HEMS. Key factors are the energy usage and number of entities in each domain. Arrows show energy distribution. Up-down-double arrows show energy trading between Home, building and Industry through the energy distribution.

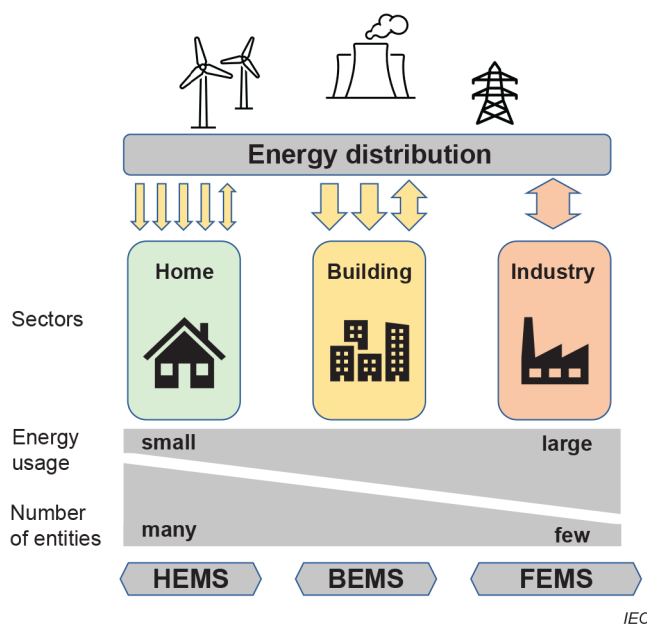


Figure 1 – Characteristic feature of HEMS, BEMS, and FEMS

The energy consumption of users of FEMS is generally larger than that of BEMS and HEMS, the effect of a single industrial entity's energy efficiency improvement is significant. The profile of energy demand varies among entities as a function of the different types of energy sources in a manufacturing facility. Typical energy sources are electricity, fuel, steam, hydro, and distributed energy resources (DER) such as renewable energy, combined heating and power stations, and storage systems to provide useful energy in the form of power, heat, steam, heating or cooling water, compressed air and similar. FEMS is usually provided as a made-to-order product. BEMS has a larger number of target entities and is readily available as a ready-made product. HEMS, which deals with a larger number of smaller entities, is a readily available mass product. Each system and associated complexity / degree of customization has a corresponding price.

Energy management in a manufacturing enterprise is performed with consideration for harmonizing many conflicting requirements such as productivity, quality, delivery, production scheduling, manufacturing cost, profit, safety, environmental and related requirements. Those requirements are prioritized depending on the corporate objectives and regulations at the time the energy management decisions are made.

In industrial facilities, the energy supply facility supplies and manages energy by managing electricity, heat, steam, hot or cooling water and compressed air to demand facilities such as production lines. The energy supply facility may be designed independently to have the capacity to meet the maximum energy demands. When the energy demand decreases, the mismatch between energy supply and demand can cause significant energy loss and decrease of energy efficiency. It is necessary to provide an optimum load balance between equipment of an energy supply facility given the energy demand. Facility energy supply can be controlled and operated based on the energy demand forecast incorporating factors such as production schedule and ambient conditions such as changes in weather.

A FEMS collects data from each level of the production system for the optimization of energy performance compared to the energy demands of the full production system. Collected data are analysed for an optimum operation of the facility to improve energy performance. There are many kinds of decision-making processes such as changing set points of equipment, changing the operating conditions of devices, selecting a manufacturing process depending on the operating situation, and others. Operating decisions are made automatically by the system or manually by operators. Guidance systems are used to support manual operation. It is expected that energy performance of an industrial facility will be improved further by making FEMS processes highly automated.

4.2 Hierarchical structure of enterprise manufacturing system

4.2.1 Levels of manufacturing enterprises and the activities

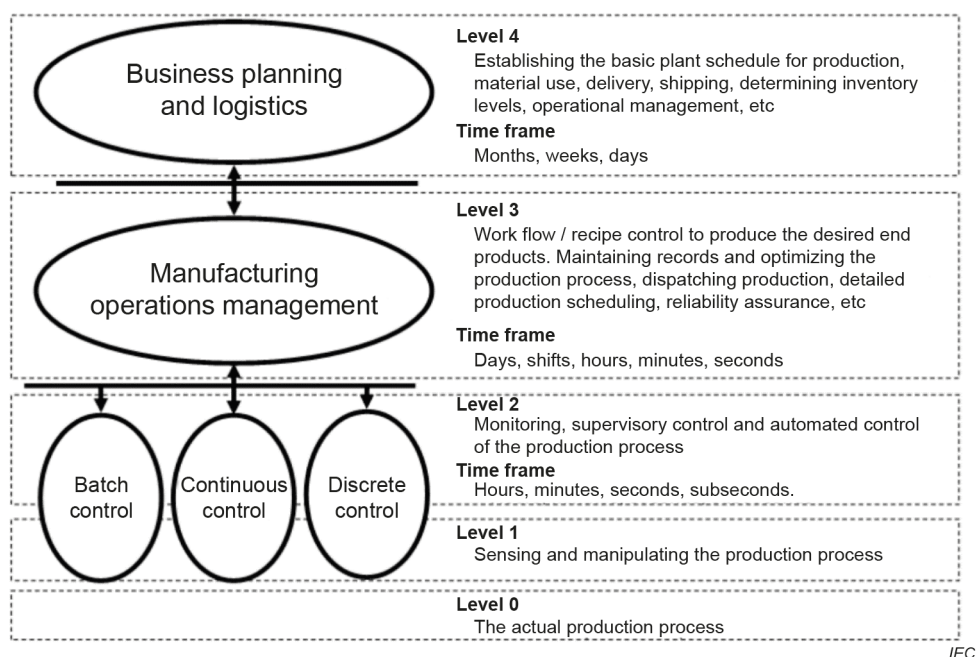


Figure 2 – Functional hierarchy

As shown in Figure 2, IEC/ISO 62264-1 (ISA-95) defines the levels for the structure of manufacturing enterprise.

FEMS is positioned on the level 3 as a part of MOM/MES. Manufacturing operations management (MOM) is a term used in IEC 62264 to specify a portion of the functional hierarchy model of a manufacturing enterprise.

FEMS exchanges information between MES, Laboratory Information Management System (LIMS), Warehouse Management System (WMS), Capability Maturity Model (CMM) systems. these level 3 systems exchange information with ERP, Advanced Planning and Optimization (APO), logistic management system in level 4 and across facilities, controllers, and sensors in level 2, 1 and 0. FEMS receives the information through MES. FEMS also exchanges information between other energy management systems and smart grid gateways which exchange information with the smart grid.

Figure 3 shows an extension to the role-based equipment hierarchy model for a variety of processes. For manufacturing operations management there are specific terms for work centres and work units that apply to continuous production, batch production, discrete or repetitive production, and for storage.

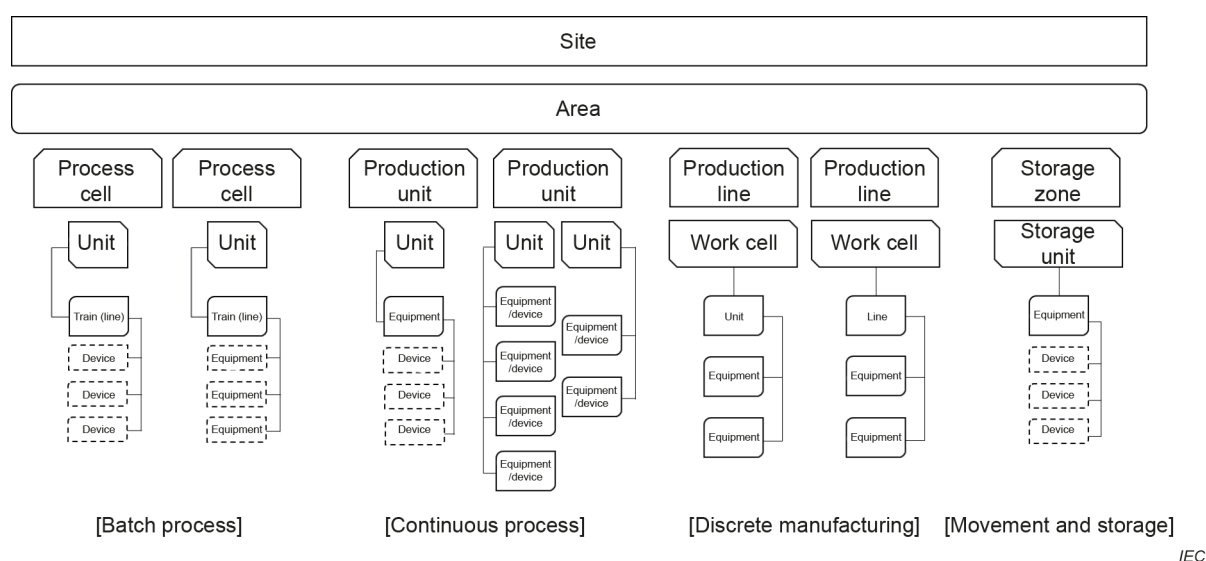


Figure 3 – Extension to the role-based equipment hierarchy model

4.3 Energy management system in a manufacturing enterprise

Manufacturing enterprises have made continuing efforts to save energy. A better understanding of how to improve the overall energy performance will lead to improving energy efficiency, minimizing waste, reducing CO₂ emissions, securing of supply and reducing overall cost. The energy management system is becoming increasingly important for further improvements of energy saving and the management of the enterprise.

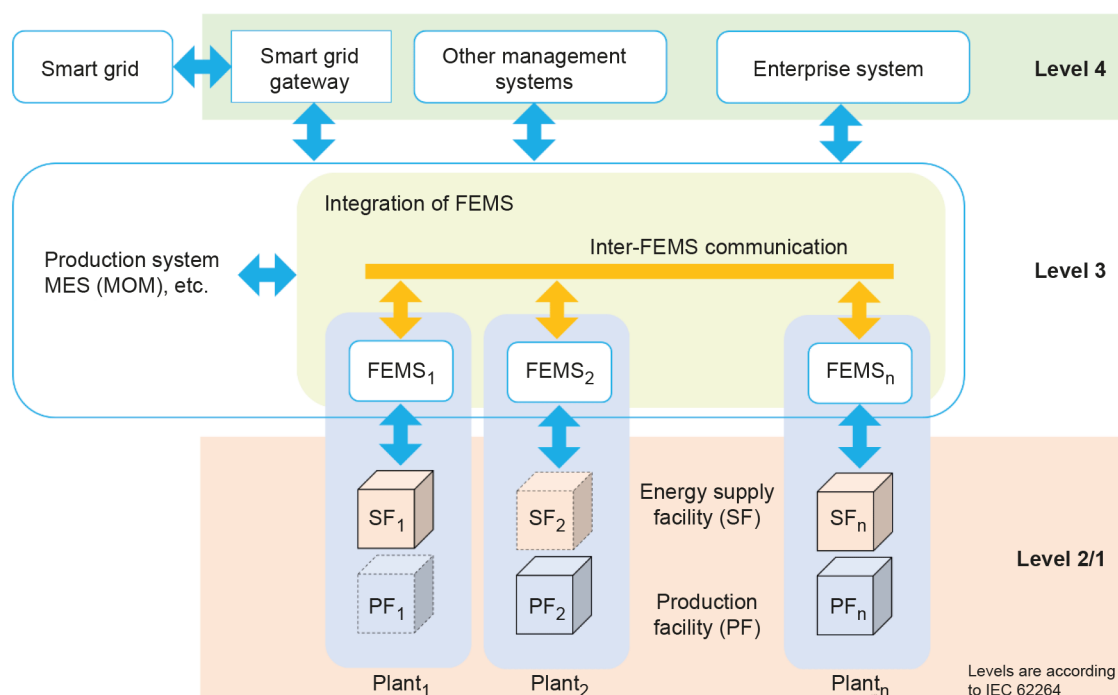
In a manufacturing enterprise, an energy management system may have been installed for a production facility every time it was needed. As an enterprise has multiple production facilities, there could also exist multiple energy management systems in the enterprise. This form of FEMS works for the individual optimization of energy performance of the single production facility.

It is expected that EMS integration will improve the overall energy performance of an enterprise to manage the operation of production systems for the changing business environment. For that, it is necessary to clarify the functions and information that are exchanged between implemented FEMS.

Figure 4 shows a general system configuration of integration of multiple FEMS in a site of an enterprise. FEMS_i covers the energy management of the Plant_i that includes energy supply facility (SF_i) and production facility (PF_i). Energy supply facility supplies energy to production plants in the necessary forms such as electricity, steam, compressed air, etc. Production facility produces products using the energy that is supplied by the energy supply facility. The energy performance of each plant is individually optimized by FEMS_i. Plant₁ shows a case in which the plant does not necessarily have a production facility. Plant₂ shows a case in which the plant does not necessarily have an energy supply facility. In such cases, the energy necessary for production in Plant₂ is supplied by Plant₁ based on the information exchanged over the Inter-FEMS communication. Necessary energy-related information exchange between FEMS is done over the inter-FEMS communication.

MOM/MES receives a total operation plan for the enterprise that optimizes the energy performance for the entire enterprise objectives such as cost and profit from the enterprise system. The total production plan is subdivided for each Plant into operation plans that is sent to each FEMS_i. FEMS_i executes the operation plan delivered from MOM/MES for the efficient energy use in Plant_i.

To exchange energy related information across multiple systems, it is necessary to standardize FEMS functions and information.



IEC

Figure 4 – System configuration of integration of multiple FEMS

4.4 Role of FEMS and its expansion

4.4.1 Role of FEMS

The role of FEMS is to improve energy performance by optimizing energy use under conditions and constraints by managing all activities within a manufacturing enterprise.

4.4.2 Expansion of the role of FEMS

Figure 5 shows the expansion of the role of FEMS.

Introduction of energy management starts by monitoring and reporting the current energy consumption status. Collected data are visualised for the energy managing activities. Collected data are also analysed and necessary manual actions are taken by operators.

During the operation of FEMS, there are some decision-making processes that are done manually by operators, engineers or maybe by managers depending on the operating situation.

To increase energy performance, FEMS has been enhanced over time by providing advanced functions such as data analysis and optimization in addition to the necessary functions of monitoring and recording.

As advanced functions are practical for FEMS, some of the decision-making processes have been automated. In Clause 5, functions of FEMS are classified by the degree of automation.

For the overall optimization of the energy performance, the system boundary for energy management should be set as wide as possible. So, it is necessary for FEMS to operate in cooperation with other systems such as other FEMS, MOM/MES, ERP, etc. Regional cooperation over the smart grid will be also necessary. In 4.5, the relations between FEMS and other systems are explained.

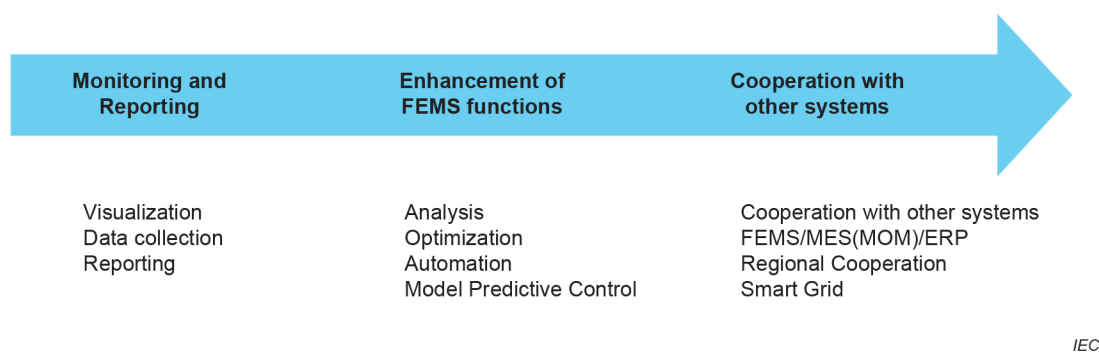


Figure 5 – Expansion of role of FEMS

4.4.3 International standardization

For greater achievement of energy savings, it is effective to have closer cooperation between related systems that exchange information. In manufacturing industries, enterprises have been pursuing productivity improvements closely related to energy savings. As supply chains have been globalized, it is necessary for enterprises in the same supply chain to exchange information on energy management with related organizations.

For a corporation, international standardization is desired for functions of FEMS and information flows in FEMS. Standardization enhances the interconnectivity with external systems, which enables advancement in optimization of energy performance across various manufacturers and enterprise boundaries that would otherwise be more difficult.

Standardizing FEMS functions and information flows will enable efficient exchange of energy related information in a facility to accelerate the upgrade and optimization of control activities in industrial facilities. FEMS can be classified depending on the level of achievement of functions so that related organizations are motivated to reach the improvement goals.

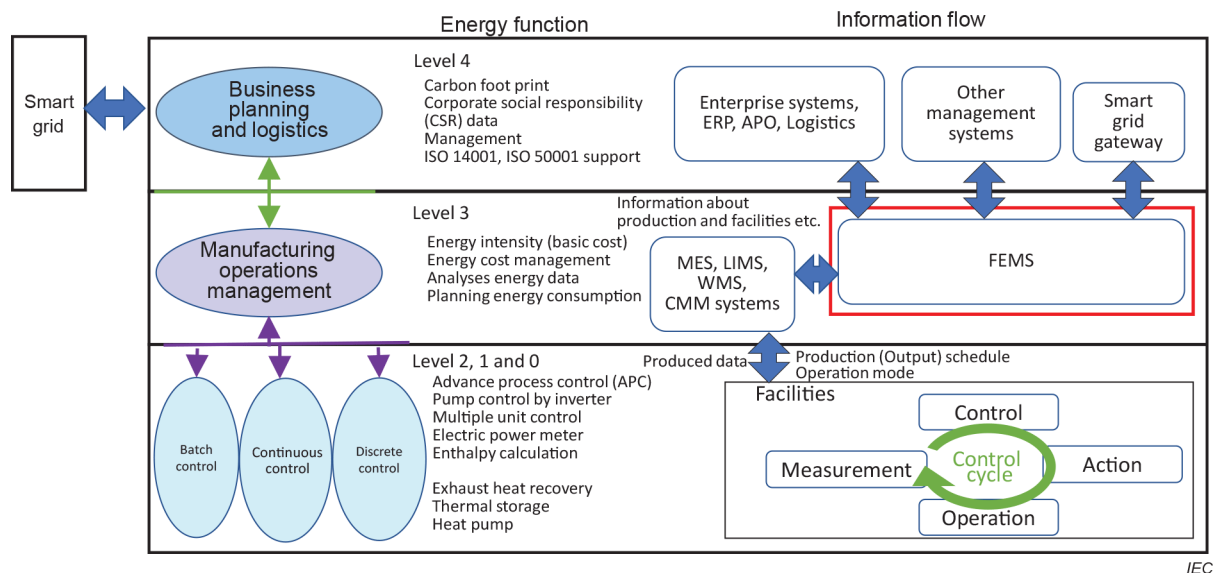
In this standard, data on energy use by facilities in factories and plants is modelled, and the exchange of data is specified to enable the distribution of information on energy used in processes in factories and plants. In addition to optimizing energy efficiency as a single facility, FEMS also enable coordinated control between multiple facilities in different locations.

4.5 Relation between FEMS and other systems

4.5.1 Relation between FEMS and other systems

Figure 6 is an expansion of Figure 2 to show the relation between FEMS and other systems such as Enterprise systems, Production systems and the Smart Grid.

FEMS can get information through other systems in Level 3 such as MES, LIMS, etc.



NOTE The red box in reflects the scope of IEC 63376.

Figure 6 – Relationship between FEMS and other systems

In factories, there are energy supply facilities such as power generator, boiler, battery, etc., and energy demand facilities such as production systems, air conditioner, heater, etc., and controllers for the facilities. Moreover, there are many systems to manage and control business planning, logistics, production operations and so on. The hierarchy model facilities are defined in IEC 62264. On the other hand, the functional hierarchy model with “Energy Function” is described in IEC TR 62837.

4.5.2 FEMS and production system

As described previously, FEMS should communicate with production systems. In the communication, FEMS receives information such as energy consumption, relevant variables, production plan, material information, etc. from many control systems, and returns an optimized scheduling plan, PV values, KPIs, etc. to them.

The production system shown in Figure 7 is a hierarchical model as defined by IEC 62264-1:2013 Enterprise-control system integration – Part 1: Models and terminology. The five production levels described in IEC 62264-1 are described on the right-hand side of Figure 7.

An enterprise is operated with management indicators such as production plan, productivity, quality, delivery, energy price, production cost, profit, environmental requirements and so on. KPI_{L4} represents Key Performance Indicators for Level 4 corresponding to these management indicators. These indicators may often include conflicting requirements. To find an optimum condition for operation, it is necessary to set priorities for those conflicting requirements depending on the business situation at that time.

KPI_{L3} represents key performance indicators for Level 3. ISO 22400 defines 35 KPIs for MES categorized by the following factors: Efficiency indicators, quality indicators, capacity index, environmental indicators, inventory management indicators and maintenance indicators.

KPI_{L2} represents Key Performance Indicators for Level 2. Process variables of the physical processes such as temperature, pressure, level, and flow, etc.

Figure 7 shows the information flow between subsystems using the notation of PV_{Li} and MV_{Lj}. PV (process variable) and MV (manipulated variable) are commonly used terminologies of process control to describe inputs and outputs of a control function.

PV_{Li} represents process variables in Level_i that are sent to the upper level (Level_{i+1}).

MV_{Lj} represents manipulated variables in Level_j that are sent to the lower level (Level_{i-1}).

To accomplish KPI_{L4}, ERP system calculates MV_{L4} that are sent to MES. Operation status of entire MES is monitored over PV_{L3} by ERP. For example, when the production volume of the enterprise is changed, ERP system changes the production schedule and sends the production schedule to MES over MV_{L4}.

To accomplish KPI_{L3}, MES calculates MV_{L3} that are sent to process control systems. After receiving the production schedule, MES generates an equipment operation plan including necessary Setpoint value (SV) of process controllers and sends the equipment operation plan to process control systems over MV_{L3}. Operation status of process control systems is monitored over PV_{L2} by MES.

To accomplish KPI_{L2}, process control systems execute control to process equipment and devices in Level 1 and Level 0.

As explained in 5.4, FEMS executes the optimization cycle through the following four categories of processes:

Monitoring→Analysis→Optimization→Instruction.

The cycle can be interpreted as a control loop with multiple variables that FEMS collects from the production system and transmits calculated data back to the production system to perform the optimization.

A Proportional Integral Derivative (PID) controller is shown in Figure 7. It is used for wide range of Level 2 process control applications. The PID controller is a Single Input Single Output (SISO) controller that calculates Manipulated Variable (MV) to achieve Process Variable (PV) equal to SV.

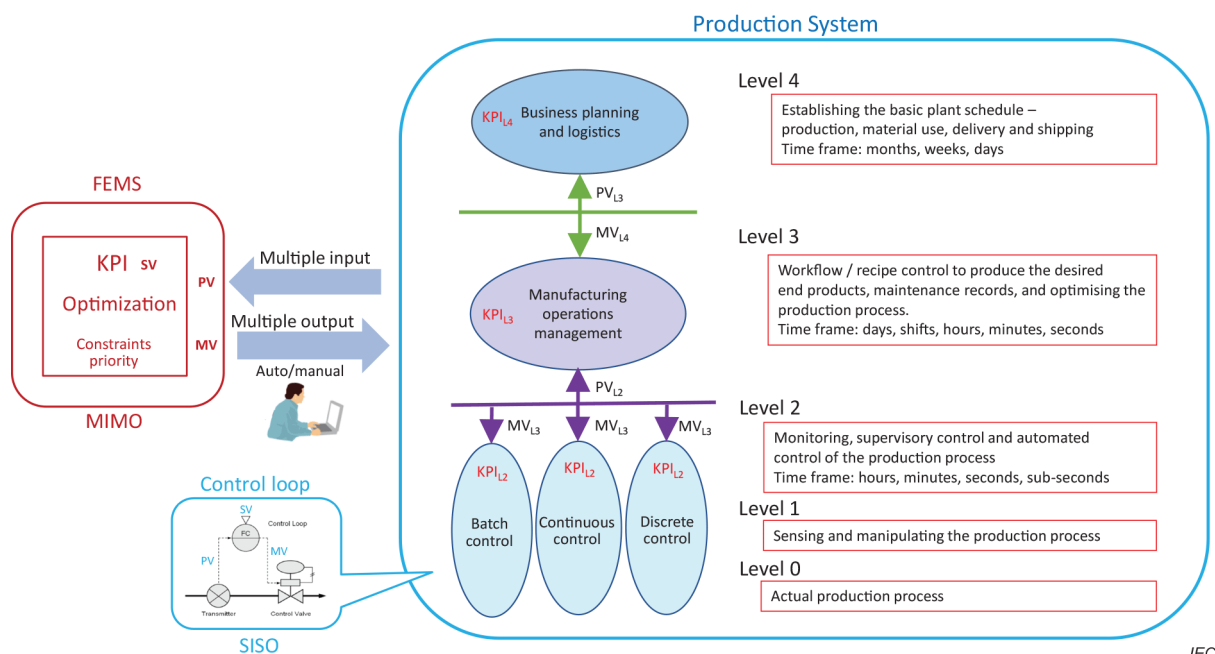


Figure 7 – Hierarchical model of production system

FEMS can be interpreted in a broad sense as a Multiple Input Multiple Output (MIMO) controller that collects multiple inputs PV ($PV_1, PV_2, \dots, PV_m$) from the production system and calculates multiple outputs MV ($MV_1, MV_2, \dots, MV_n$) that are sent to the production system to perform an optimized operation for targeted KPIs. SV ($SV_1, SV_2, \dots, SV_k$) are the set (target) values of KPIs to be optimized under the given constraints.

The optimization process is done through several decision-making processes such as determining the target values of KPIs and related process operations. Practically, some of the decisions are made manually by the operator or engineer who are responsible for the process operation. These decision-making processes are expected to eventually be automated by FEMS with the enhanced functions including control.

Model Predictive Control (MPC) is one example of MIMO control with constraints [5].

MPC-based FEMSs have been documented for practical energy management applications.

Figure 8 shows a block diagram of Multiple-input, Multiple-output Controller.

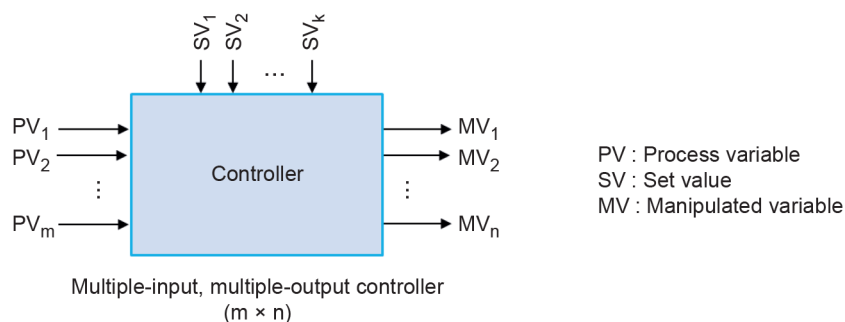


Figure 8 – Multiple-input, Multiple-output controller

4.5.3 Management and optimization

For process operation, set values of controllers are set by a process operator manually or by the MOM/MES automatically. It can be said that process control is keeping the process on the set value, process management is keeping the set value of the process at an optimum (profitable) point. A process control system has several controllers with their own set points that are set to obtain optimum operation.

Process operation is executed in accordance with the operating procedures. There are decision making processes such as selecting an optimum operation procedure and setting optimum setpoints for controllers. These decision-making processes have been done by process operators and/or engineers manually with the information supported by the process management system such as MOM/MES including FEMS. However, the advancement of processing power of management systems has enabled the automation of the decision-making processes in the management systems. For example, MPC-based EMS has been put into practical use. FEMS as a MIMO optimization controller for production systems is explained in 4.5.2.

The level of automation of FEMS is introduced based on the level of automation in Clause 6.

4.6 Information exchange

4.6.1 System boundary

In order to evaluate the energy performance of a system, it is necessary to define boundaries for evaluating the energy performance. Depending on the energy management requirements, the boundary could be a device, machines/equipment, a production line, or the entire enterprise.

Figure 9 depicts the hierarchical structure of integrated enterprise-production system and examples of system boundaries based on the functional hierarchy defined by IEC 62264.

Information exchange between upper and lower levels of the hierarchy is done through PV and MV. PV (Process Variable) represents the information as a report to the upper level from the lower level. MV (Manipulated Variable) presents the information to the lower level from the upper level as an order to the lower level.

B4 is the boundary for an entire enterprise system. In B4, there are MESs on Level 3 that are connected to ERP on level 4. B3.1 is the boundary that is covered by MES1 on Level 3. There are Process Control Systems on Level 2 that are managed by MES1 within B3.1. B2.1.1 is the boundary that is covered by PCS2.1.1 in B2.1.1. PCS2.1.1 performs control function communicating with units of field devices such as sensors/actuators. B2.1.1.1 is the boundary that is defined for a process controller. The process controller receives PV1.1.1 from a transmitter and calculate MV2.1.1 that is sent to the control valve to keep $PV1.1.1 = SV2.1.1$. SV is the set value of the controller.

SV2.1.1 can be changed to managed for overall optimisation by the MES.

There are KPIs for the operation of each level. KPI4 represent a set of KPIs in the ERP system in the boundary B4. KPI 3.1 represent a set of KPIs in the MES1 in the boundary B3.1. KPI2.1.1 represent a set of KPIs in the process control systems in the boundary B2.1.1.

For normal operation, systems on each level are operated to achieve the KPIs individually.

Optimization theory says that the local minima do not necessarily lead to a global minimum.

For overall optimization, these KPIs are related to each other and together must be managed by a FEMS or similar system.

FEMS calculates KPIs for each boundary to understand energy efficiency and evaluate energy utilization in each boundary. Some FEMS predict future energy consumption based on historical data of energy and relevant variables. Depending on the prediction results, certain FEMS calculate and suggest optimised production plans, energy consumption under the optimised production plans, future energy savings using the received production plan from MES and predicted relevant variables (e.g., humidity, temperature, weather, etc.) to fulfil constraints from top management and of facilities. This optimized production plan is sent to other management systems in level 4 and level 3 through MES. The FEMS can also calculate setting values for facilities. These setting values are sent to the controller and facilities in level 2, 1 and 0 through MES.

When some of KPI4 such as the total energy consumption of the enterprise is changed, related KPIs of KPI3.1 such as the production plan can be changed by ERP via MV4.3.1. Followed by the change of production plan, related KPIs of KPI2.1.1 such as set value SV2.1.1 can be changed by MES1 via MV3.2.1. The process is controlled on the new set value. This is an example of overall optimization. For overall optimization, it is effective to define the boundary wider as necessary.

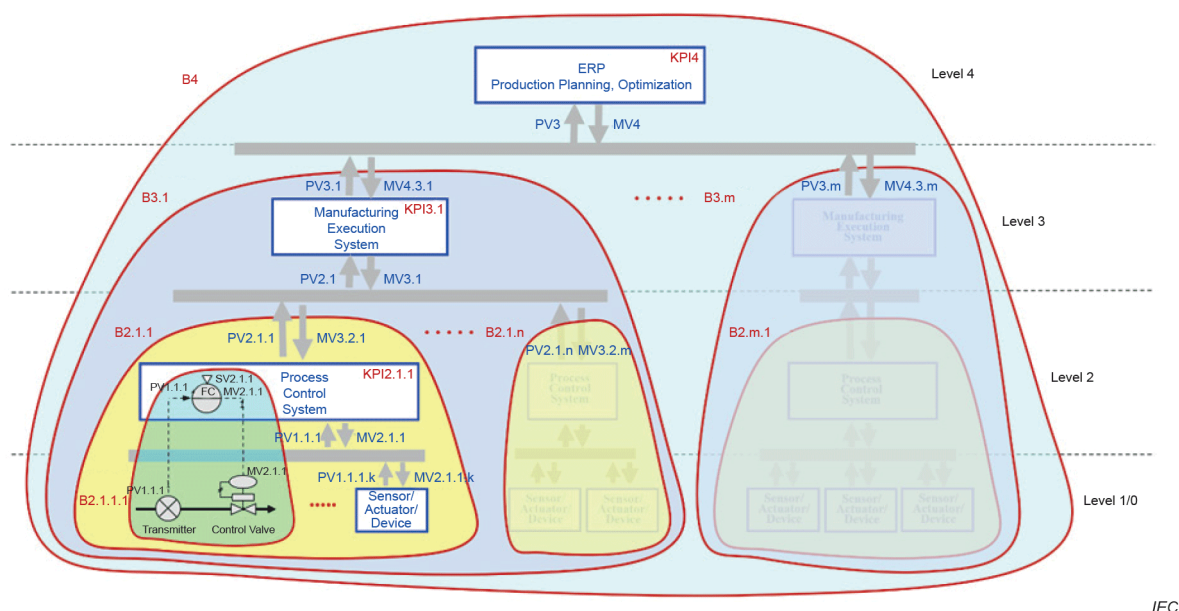
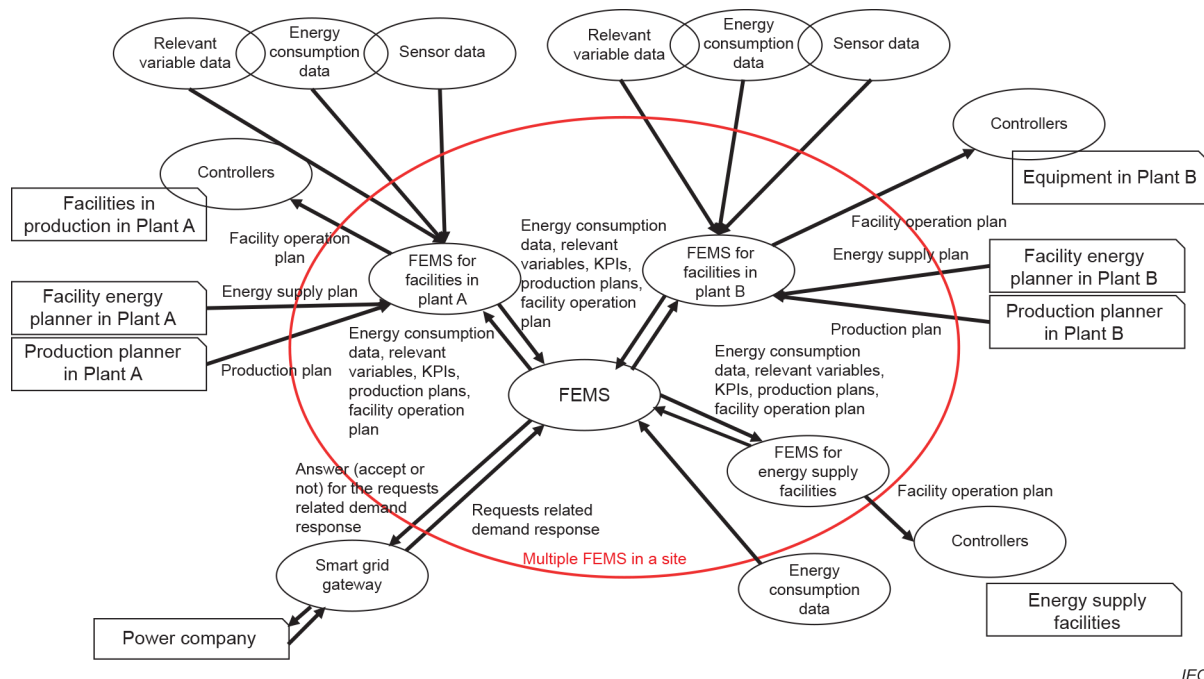


Figure 9 – Hierarchical structure of integrated enterprise-production system

4.6.2 Inside and outside of the facility

Figure 10 depicts an example of multiple FEMS in a site of an enterprise. FEMS-A works for the energy management of Plant-A and optimizes energy performance of Plant-A. FEMS-B works for the energy management of Plant-B and optimizes energy performance of Plant-B. FEMS-E works for the energy management of Energy Supply Facility that supplies energy to Plant-A and B. When the Energy Supply Facility generates surplus power to the total demand of Plant-A and B, the surplus power is sold to the power company by Demand Response. FEMS-D, by exchanging information with FEMS-A, B and E, works for the Demand Response management to the outside power company. Information exchange with inside/outside of the facility enables to achieve overall optimization of energy performance of the enterprise.



IEC

Figure 10 – Example of Information exchange with inside and outside of the facility

Figure 10 shows representative FEMS data exchanges between systems inside and outside of facilities.

4.7 Data confidentiality

4.7.1 General

Data confidentiality includes a wide range of data types that can be considered as intellectual property (IP). The forms of IP are patents, copyrights, and trademarks, which are all placed in the public domain as such. However, in many cases other forms of IP such as industrial designs, trade secrets as well as geographical information and by association personal information, also need to be protected. It is the last two elements of geographical and personal information that are most difficult to protect in a fully integrated system such as FEMS.

Because for some organizations, energy cost account for a substantial portion of their operating cost, FEMS should consider their energy consumption is confidential data. Each KPI should be confirmed to be able to disclose to the third parties based on the calculation data and method. Moreover, FEMS should also incorporate information security. IEC and ISO standards related to information security are identified in 4.7.2.

When an organization is required to disclose KPIs calculated with energy consumption data, normalized index values, percent changes from the stated reference year, etc. are listed, and single or multiple relevant variables for showing results of their energy efficiency improvement, the data confidentiality needs to be maintained while still representing the necessary trends. Normalized index values of energy consumption are one commonly used technique for keeping the confidentiality. This normalized index value is predicted energy consumption divided by energy consumption in a reference condition. When using this index, the actual value of energy consumption can be kept secret by having only those parties (i.e., between energy supply and consuming companies) share the reference conditions.

Percent changes from the criterial year also used for disclosing results of energy efficiency improvement of facilities, site, producing process and so on. To compare multiple data of the percent change, the criterial year should be determined and updated if their energy use is changed.

4.7.2 Information security

Data confidentiality is one aspect of the overall cybersecurity structure required of any computer based or digital system. Because FEMS will be integrated with broader business systems, they will need to be aware of and compliant with cybersecurity standards including ISO 27001, ISO 27002, ISO 22301, and ISO 27032. (Information security management systems), and the IEC 62443 series.

Figure 11 shows the IEC 62443 series and where the parts are applied in practice. These documents should be used for FEMS cybersecurity.

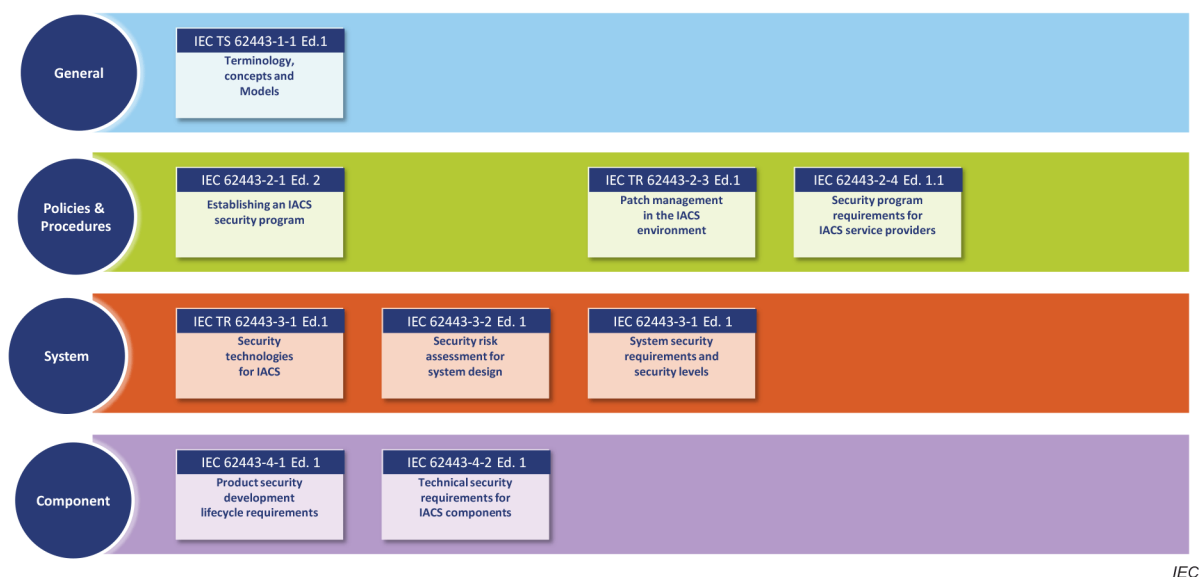


Figure 11 – IEC 62443 Security for industrial automation and control systems standards

5 Description of functions of FEMS

5.1 Category of functions of FEMS

Figure 12 depicts the categories of FEMS functions and improvement cycle of energy performance.

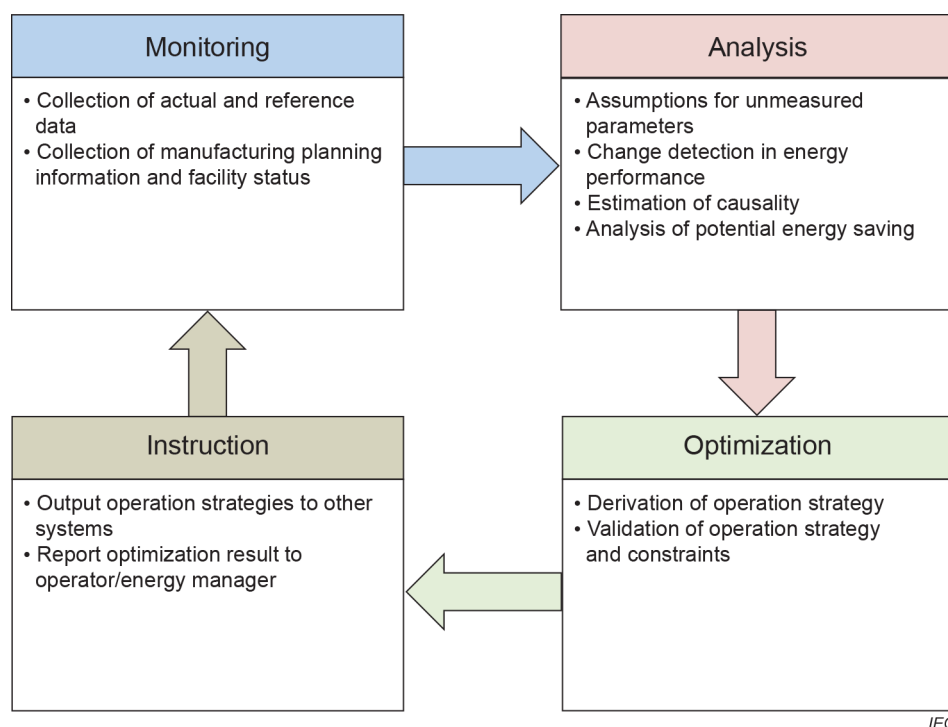


Figure 12 – Categories of FEMS functions and improvement cycle of energy performance

The role of FEMS is to improve energy performance by optimizing energy use under conditions by managing activities within a manufacturing enterprise. In order to carry out the role, FEMS has necessary functions that are summarised in 10 functions specified in the bulleted lists in each FEMS category in Figure 12. These functions are classified into four categories, which are Monitoring, Analysis, Optimization and Instruction. Table 1 describes each FEMS function category.

Table 1 – Description for FEMS function categories

FEMS Category	Description
Monitoring	Functions for collecting actual and reference data for energy consumption and relevant values following facilities operation from other systems and storing the data in the FEMS database.
Analysis	Functions for analysing energy performance of facilities, estimating causality between the energy consumption and the relevant variables, and exploring potential for energy saving.
Optimization	Functions for deriving optimal operation strategies based on operation plan made by other system according to constraints from top management and validating the operation strategy with simulation if it is required.
Instruction	Functions for transmitting and reporting setting parameters and operation for each facility based on the deviated operation strategy and reporting the results of the analysis.

Details of each function in the categories are as follows:

1) Monitoring:

- Collection of actual and reference data

FEMS collects actual and reference data such as the amount of energy supply from energy supply equipment, energy consumption of production equipment for the production quantity, process, and machine data and related information as from ISO 20140-5 for the classification of environmental performance evaluation (EPE) data. These data are collected through MES.

- Collection of manufacturing planning information and facility status

FEMS collects operational status and scheduling information such as energy price, production plan, production equipment and related information for energy management and target and goals inputted from top management. This information is collected from LIMS, WMS, CMM and other FEMS's.

Collected data are time-stamped and stored in the FEMS database. Stored data in the database can be accessed by the functions of FEMS and used for the generation of calculated data that are also stored in the database.

2) Analysis:

- Assumptions for unmeasured parameters

Based on the data collected by the functions of "Monitoring", FEMS estimates values of unmeasured parameters using the data stored in the database.

- Change detection in energy performance

Based on the data collected by the functions of "Monitoring", FEMS calculates KPI for each boundary and energy baseline for the reference of energy management. FEMS detects the change in energy performance using the KPIs and baseline.

- Estimation of causality

When change is detected, FEMS estimates the causal relation between the change and the operation status of energy supply equipment and production equipment and actual production.

- Analysis of potential energy savings

Based on the estimation, FEMS analyses the potential of energy savings to be optimised.

3) Optimization:

- Derivation of operation strategy

Based on the results analysed by the functions of "Analysis", FEMS derives operation strategies. Prior to the actual production, FEMS estimates the energy consumption and CO₂ emission for the production plan. If the energy consumption estimated by FEMS is not optimum within the constraint conditions that are set by the organization, the production plan will be re-examined. Cost reduction, productivity, CO₂ emission reduction, etc. are included in the constraint conditions that are prioritized for operations.

- Validation of operation strategy and constraints

The FEMS validates the effectiveness of the production plan re-examined by individual FEMSs to meet the constraints of equipment.

4) Instruction:

- Output operation strategies to other systems

The FEMS outputs the validated production plan that specifies operating conditions of energy supply equipment and production equipment to other systems through MES.

- Report optimization results to operator/energy manager

The FEMS sends reports about KPIs of boundary and related information to energy manager and equipment operators.

Figure 13 shows an example of relationships among the functions of the FEMS and other systems.

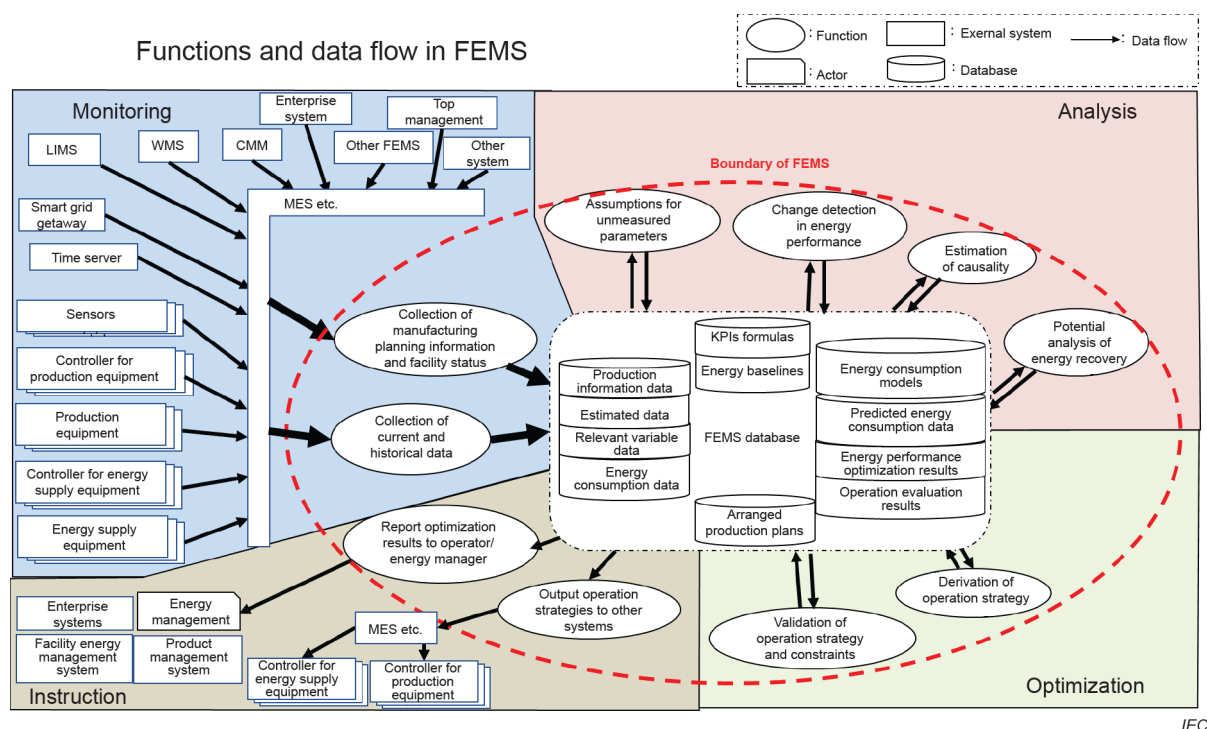


Figure 13 – Relationship among functions of FEMS and other systems

The following functions in the category of “Monitoring” collect data from energy supply equipment, production equipment, sensors, Smart grid, LIMS, WMS, CMM, Enterprise system, other FEMS, etc. These data are collected through MES and stored in the FEMS database.

- Collection of actual and reference data

Collection of manufacturing planning information and facility status Functions in other categories calculate output data using the data in the FEMS database and store the output in the FEMS database.

5.2 Monitoring Data Flows

5.2.1 General

Table 2 and Figure 14 show examples of data input to and output from FEMS functions categorized in “Monitoring”.

Table 2 – Data input and output of FEMS functions categorized into “Monitoring”

Functions	Data Input to the functions	Data output from the functions
Collection of actual and reference data	Energy consumption Related data Sensor data	Time-stamped data
Collection of manufacturing planning information and facility status	Production plan, Operation status Scheduling information Energy management information Weather forecast Organizations targets and goals	Production information

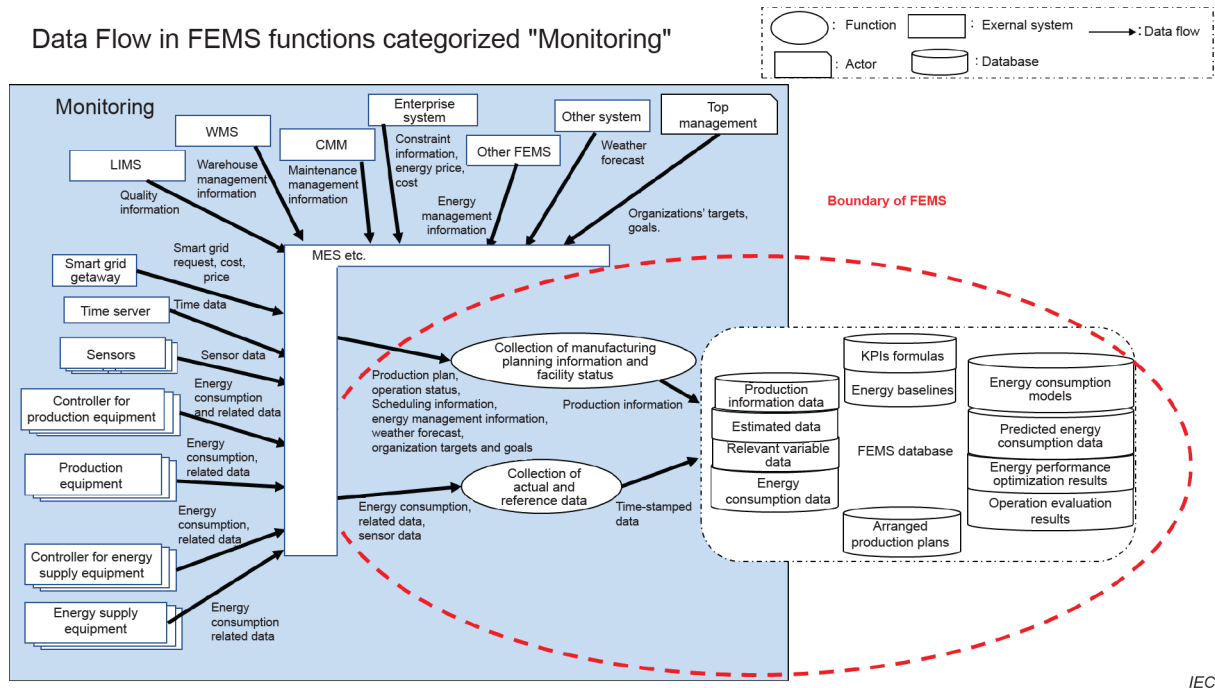


Figure 14 – Functions categorized under “Monitoring” and FEMS related data flow

5.2.2 Collection of actual and reference data

5.2.2.1 Requirements

This function shall collect energy-related data such as energy consumption, plus relevant data and variables, from control equipment and sensors via the MES.

NOTE 1 Relevant variables include environmental information such as atmospheric temperature, humidity, etc. during the production. The unit of collected data is converted into predefined engineering unit and timing data.

EXAMPLE: Conversion into timing data might be executed every hour by aggregating the data per minute.

The formats of collected data are converted into the FEMS data format.

NOTE 2 Each data element is timestamped for the format conversion. Aggregated data are stored in the specified FEMS database.

5.2.2.2 Data flow

Considerations on inputs and outputs:

Input:

- Energy consumption: Energy supply and consumption of energy supply equipment, and Energy consumption of energy demanding equipment such as production equipment
- Related data: Relevant variables that affect energy demand and supply (production volume)
- Sensor data: Relevant variables from sensors that affect energy demand and supply (atmospheric temperature, humidity, etc.)

Output (into the FEMS database):

- Time-stamped data

5.2.2.3 Processing

Collecting energy and relevant information, conversion of data format and storing the data in the FEMS database.

5.2.3 Collection of manufacturing planning information and facility status

5.2.3.1 Requirements

This function shall obtain the related information such as production plan (target and constraints), equipment and operating information, etc. by collecting data from other systems.

NOTE 1 Equipment information contains production volume, result values (e.g. processing speed, operation mode, pre-set temperature) of equipment from which the FEMS can get information.

NOTE 2 Production plan information contains production schedule that the FEMS can get from other systems.

NOTE 3 Related energy management information including purchase cost of fuel, CO₂ emission, results of composition analysis of raw material and fuel, etc.

The following information is obtained:

- Information to define boundary (equipment and devices, etc), maintenance plan and records
- Information about constraints in daily manufacturing and energy procurement from outside of the organization
- Information about production plan, equipment operation plan and predicted relevant variables (weather forecast, atmospheric temperature, etc.) for the execution of these plans are obtained

Totalised data are stored in a specified database.

5.2.3.2 Data flow

Considerations on inputs and outputs:

Input:

- Production plan
- Operation status: Operating conditions of production equipment (planned production volume at a given time, results of composition analysis of raw material and fuel (e.g., moisture content, etc.)
- Scheduling information: operation plan of production equipment and maintenance plan
- Energy management information: Boundary configuration, parameters records of equipment, constraints (cost, CO₂ emission, energy consumption, etc.), and predicted value of relevant variables
- Weather forecast
- Organization targets and goals: Information about external procurement of energy

Output (stored in the FEMS database):

- Production information collected from other systems: Operation and status

5.2.3.3 Processing

Operation conditions of equipment, results of production are stored in the FEMS database.

5.3 Analysis Data Flows

5.3.1 General

Table 3 and Figure 15 show examples of data input to and output from FEMS functions categorized in “Analysis”.

Table 3 – Data input and output of FEMS functions categorized into “Analysis”

Functions	Data Input to the functions	Data output from the functions
Assumptions for unmeasured parameters	Time-stamped data, Production information	Estimated data
Change detection in energy performance	Energy consumption Energy supply relevant variables Production information Production plan Estimated data KPI definition	KPI value, Energy baseline
Estimation of causality	Energy consumption Energy supply relevant variables Production information Production plan Estimated data KPI definition	KPI value Energy baseline Causality analysis result
Analysis of potential energy saving	Energy consumption Energy supply relevant variables Production information Production plan Estimated data KPI definition	KPI value, Energy baseline, Energy saving based on causality analysis

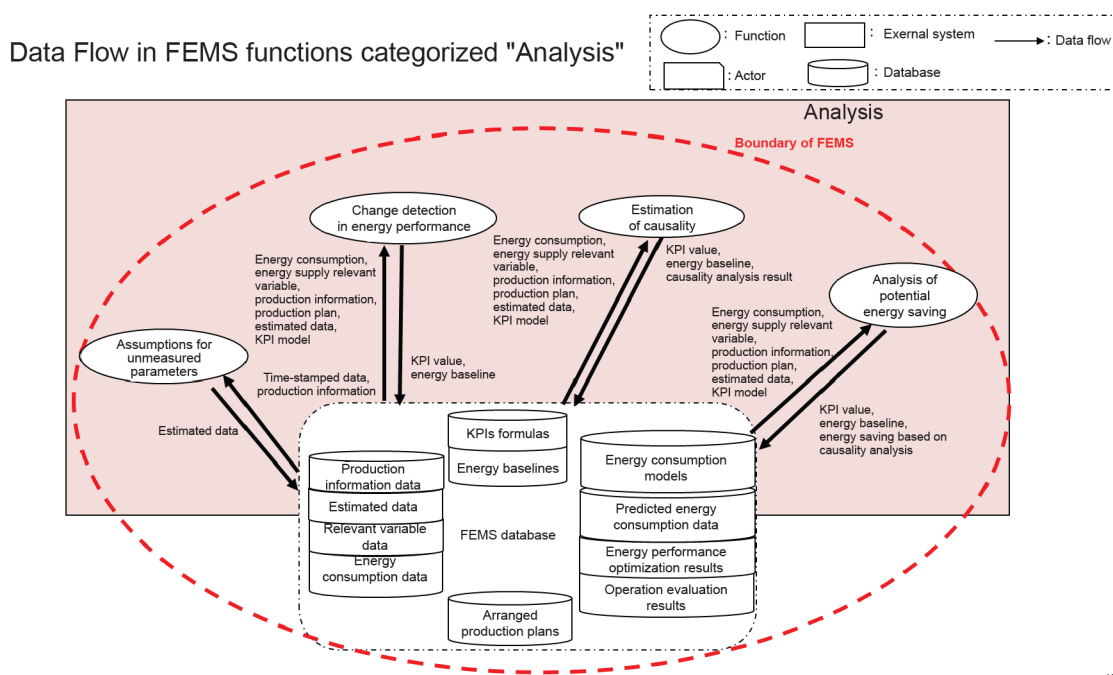


Figure 15 – Functions categorized under “Analysis” and FEMS related data flow

5.3.2 Assumption for unmeasured parameters

5.3.2.1 Requirements

This function shall estimate unmeasured data and parameters due to the lack of direct measurement means based on other measured data.

EXAMPLE 1: A case where unit energy cost is calculated using fuel cost, energy efficiency and energy output of energy supplying equipment.

EXAMPLE 2: A case where input power consumption of the whole facility is measured and allocated to multiple production equipment units proportionally to each individual production status. Energy disaggregation decomposes the measured total consumption into the individual contribution of each equipment/device by statistical approaches.

EXAMPLE 3: A case where coal consumption is calculated by the inventory before and after production.

EXAMPLE 4: Estimation of the energy consumption of a production equipment based on the operation status of equipment every 10 minutes and accumulated hourly energy consumption.

5.3.2.2 Data flow

Considerations on inputs and outputs:

Input:

- Time-stamped data: Energy consumption and supply of energy from supplying equipment
- Production information: Operating conditions of production equipment (e.g. processing speed, operation mode, pre-set temperature), KPI definition

Output (stored in the FEMS database):

- Estimated data: Estimated unmeasured data

5.3.2.3 Processing

Calculation results for unmeasured parameter are stored in the FEMS databases.

5.3.3 Change detection in energy performance

5.3.3.1 Requirements

This function shall detect changes in energy performance of boundary using the data in the FEMS

EXAMPLE: To calculate KPIs values of boundary. To generate alarms when the deviation between current value of KPI and the baseline exceeds the allowance.

NOTE KPIs include energy consumption, energy consumption intensity, statistical model, etc.

5.3.3.2 Data flow

Considerations on inputs and outputs:

Input:

- Energy consumption: Energy consumption of energy consuming equipment such as production equipment
- Energy supply relevant variables: parameters, operating conditions of production equipment and actual values
- Production information: Boundary configuration
- Production plan
- Estimated data: result of Estimation results for unmeasured data such as composition analysis of raw material and fuel (e.g. moisture content),
- KPI definition: Model equation of KPI, Baseline, Calculated result of KPI value

Output: (stored in the FEMS database):

- KPI values
- Energy baseline

5.3.3.3 Processing

Energy baseline shall be calculated using historical data.

Deviation between KPI value and energy baseline shall be calculated.

5.3.4 Estimation of causality

5.3.4.1 Requirements

This function shall estimate the causal relationship between operating status of boundary, energy consumption and relevant variables.

EXAMPLE: Causality is estimated based on the change before and after the abnormal data detected by the check of KPI results and the baseline.

5.3.4.2 Data flow

Considerations on inputs and outputs:

Input:

- Energy consumption: Energy consumption and supply of energy supplying equipment, and energy consumption of energy consuming equipment such as production equipment
- Energy supply relevant variables: Relevant variables that affect to energy demand and supply (e.g. production volume, atmospheric temperature, humidity, etc.), estimation results for unmeasured data
- Production information: Result of composition analysis of raw material and fuel (e.g. moisture content), and boundary configuration
- Production plan: parameters
- Estimated data:
- KPI definition: Historical data of baseline, model equation of KPI, baseline, calculated result of KPI, confirmed effectiveness of KPI and baseline

Output: (stored in the FEMS database):

- KPI values
- Energy baseline
- Causality analysis results

5.3.4.3 Processing

The causal relationship between operating status of boundary, energy consumption and relevant variables shall be estimated.

Relational expressions based on the causality analysis of energy information and relevant variables shall be generated.

5.3.5 Analysis of potential energy saving

5.3.5.1 Requirements

This function shall estimate possible energy saving after eliminating the cause of change based on the causality analysis.

EXAMPLE: When results of KPI exceed the allowable range of the deviation from baseline, possible energy saving is estimated by setting optimum operating conditions of equipment and activating cooperative operation of multiple equipment units based on the past operation data.

- Energy consumption and supply of energy supplying equipment
- Energy consumption of energy consuming equipment such as production equipment
- Relevant variables that affect energy demand and supply (e.g. production volume, atmospheric temperature, humidity, etc.) Operating conditions of production equipment (e.g. processing speed, operation mode, pre-set temperature), Production plan, Estimation results for unmeasured data
- Historical data of baseline, Model equation of KPI

5.3.5.2 Data flow

Considerations on inputs and outputs:

Input:

- Energy consumption
- Energy supply relevant variables
- Production information
- Production plan
- Estimated data
- KPI definition

Output (stored in the FEMS database):

- KPI value
- Energy baseline
- Energy saving based on causality analysis

5.3.5.3 Processing

To estimate possible amount of energy saving based on the following calculations.

- To compare the latest data and baselines
- To estimate possible operating conditions of equipment such as set values and constraints on the operation based on the equipment maintenance information and relation between operation results and the past value of KPI
- To estimate current energy consumption from the energy consumption and the latest data that are estimated under the above conditions

5.4 Optimization Data Flows

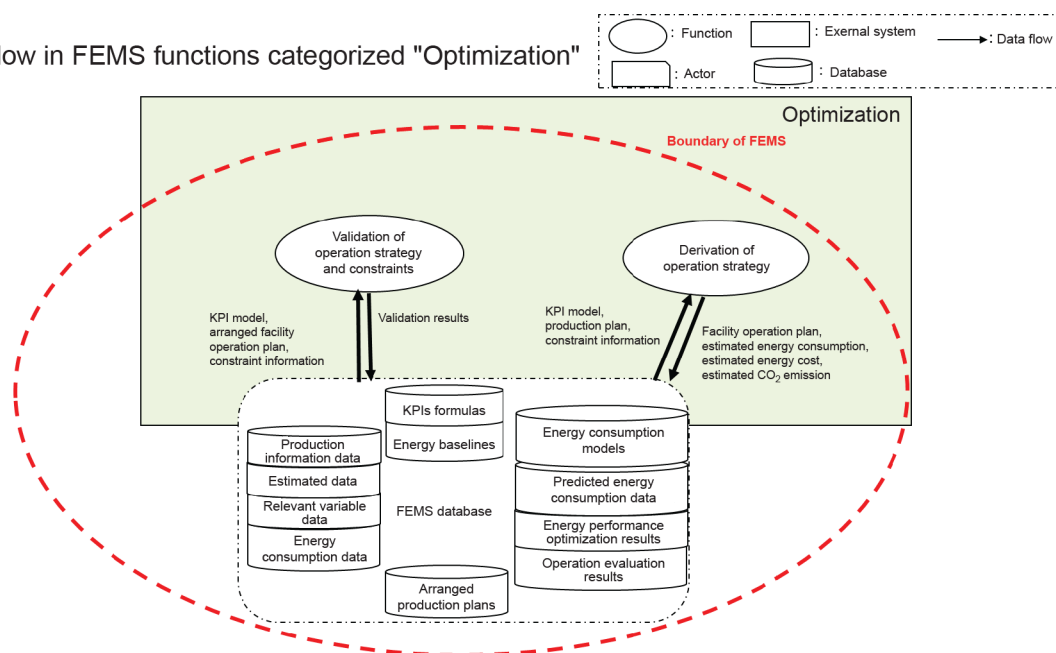
5.4.1 General

Table 4 and Figure 16 show examples of data input to and output from FEMS functions categorized in “Optimization”.

Table 4 – Data input and output of FEMS functions categorized into “Optimization”

Functions	Data Input to the functions	Data output from the functions
Validation of operation strategy and constraints	KPI definition Arranged facility operation plan Constraint information	Validation results
Derivation of operation strategy	KPI definition Production plan Constraint information	Facility operation plan Estimated energy consumption Estimated energy cost Estimated CO ₂ emission

Data Flow in FEMS functions categorized "Optimization"



IEC

Figure 16 – Functions categorized under “Optimization” and FEMS related data flow

Derivation of operation strategy:

5.4.2 Validation of operation strategy and constraints

5.4.2.1 Requirements

This function shall validate equipment operation plan to meet the requirements of constraints on equipment, cost, CO₂ emission, etc.

5.4.2.2 Data flow

Considerations on inputs and outputs:

Input:

- KPI definition: Model equation of KPI
- Arranged facility operation plan: equipment operation plan
- Constraint information: predicted values of equipment operation under the constraints on the equipment operation

Output (into the FEMS database):

- Validation results: Results of the validation of equipment operation plan with the following data, Energy consumption of each equipment, production cost, calculated values of CO₂ emission, constraints on equipment operation

5.4.2.3 Processing

Validation of the operation strategy under the constraints by comparing planned values and actual results of equipment operation, after the equipment operation plan has been carried out under the constraint conditions.

5.4.3 Derivation of operation strategy

5.4.3.1 Requirements

This function shall derive an equipment operation plan that optimizes energy consumption under the constraints of production plan such as safety, quality, etc.

5.4.3.2 Data flow

Considerations on inputs and outputs:

Input:

- KPI definition: Model equation of KPI
- Production plans: production plan
- Constraint information: predicted relevant variables such as production volume, temperature, humidity, etc., constraints on equipment operation, information about external procurement of energy

Output (into the FEMS database):

- Facility operation plan: Results of the investigation on the equipment operation plan
- Estimated energy consumption: calculation results of energy consumption under the equipment operation plan
- Estimated energy cost: calculation results of energy cost under the equipment operation plan
- Estimated CO₂ emission: calculation results of CO₂ emission under the equipment operation plan

5.4.3.3 Processing

To estimate energy consumption of the entire facility by totalizing the predicted quantity of energy consumption based on the given production plan.

To review the changes of the production plan, operation plan, external energy supply, when operating conditions of boundary are inconsistent with the constraints on equipment operation.

5.5 Instruction Data Flows

5.5.1 General

Table 5 and Figure 17 show examples of data input to and output from FEMS functions categorized in “Instruction”.

Table 5 – Data input and output of FEMS functions categorized into “Instruction”

Functions	Data Input to the functions	Data output from the functions
Report optimization results to operator/energy manager	KPIs Baselines Verification results Arranged facility operation plan etc.	Reports
Output operation strategies to other systems	Arranged facility operation plan	Translated facility operation plan, Setting parameters

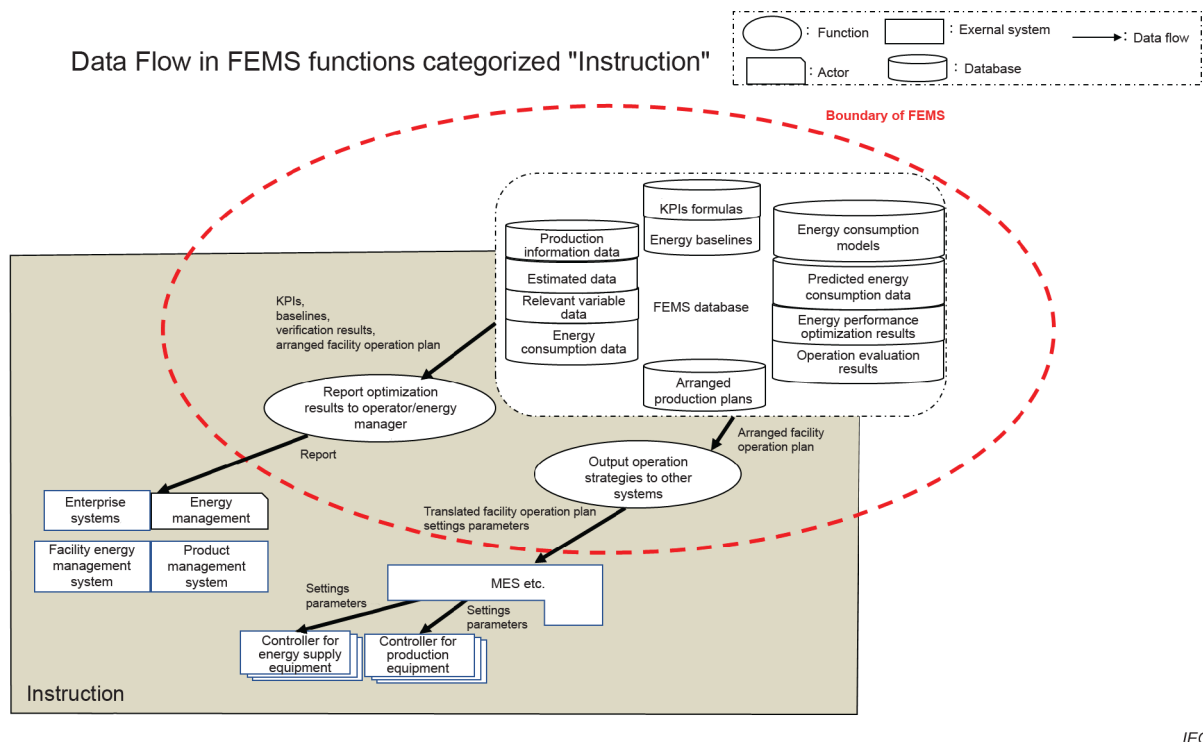


Figure 17 – Functions categorized under “Instruction” and FEMS related data flow

5.5.2 Report optimisation results to operator/energy manager

5.5.2.1 Requirements

This function shall provide persons concerned (operator, manager, etc.) with a report of KPI results such as energy consumption, energy consumption intensity, etc.

5.5.2.2 Data flow

Considerations on inputs and outputs:

Input:

- KPIs
- Baselines
- Verification results
- Arranged facility operation plan: Changed set point data for equipment operation to carry out the production plan and equipment operation plan that are optimized in the FEMS

Output:

- Reports: Set values at the execution timing of production equipment and energy supply equipment for carrying out the production plan and the equipment operation plan, energy related information, relevant variables, KPIs, baselines, optimized production plan, alarm of non-achievement of production plan, and information for equipment maintenance

5.5.2.3 Processing

This function shall output the report of totalized calculation results of energy related information and relevant information.

5.5.3 Output operation strategies to other systems

5.5.3.1 Requirements

This function shall output set values for equipment operation based on the production plan to other systems.

5.5.3.2 Data flow

Considerations on inputs and outputs:

Input:

- Arranged facility operation plan: Equipment operation plan that is optimized in the FEMS, setting values of equipment for the optimised operation of equipment

Output

- Arranged facility operation plan
- Setting parameter: Set values at the execution timing of production equipment and energy supply equipment for carrying out the equipment operation plan

5.5.3.3 Processing

To derive set values of production and energy supply equipment at a given time to carry out the equipment operation plan that is optimized in the FEMS.

6 Classification of FEMS

Classification of FEMS is based on three aspects which are function, automation level and boundary. The items in the function axis are the same as FEMS function categories described in Table 1. The items in automation axis are the “automation levels” in the FEMS process. Table 6 describes the “Automation levels”. The items in the boundary axis are defined in 3.1.

Table 6 – Description of “Automation levels”

Autom ation level	Management mode	Narrative definition	Monitoring	Analysis	Optimization	Instruction
Human manager mainly performs four of the fundamental functions of FEMS.						
0	Manual mode	Energy-manager performs all aspects of the energy management task	Manager	Manager	Manager	Manager
1	FEMS assisted mode	System collects actual data and visualizes it to assist energy manager	Partially done by system	Manager	Manager	Partially done by system
2	Partial automation mode	System monitors and estimates unmeasured data/parameters. System visualizes KPI and actual/reference data	System	Partially done by system	Manager	Partially done by system
System perceives the facility state by monitoring and analysis and derives operation strategies by optimization to instruct other systems						
3	Conditional automation mode	System can perform all management tasks, including collaborative optimization with multiple systems in the steady-state operation or certain batch phases. Manager still needs to respond appropriately to the system's requests, etc.	System	Partially done by manager	Partially done by manager	Partially done by manager
4	High automation mode	System performs all managing tasks within certain boundaries If constraints are not satisfied under the production plans, the equipment operation plan are adjusted by manual	System	Normally done by system	Normally done by system	System
5	Full automation mode	System performs all managing tasks	System	System	System	System

Figure 18 shows a three-dimensional map of FEMS that is a representation of a three-dimensional cartesian coordinate system with the X-axis pointing towards the functions, Y-axis for automation level and Z-axis for boundary.

The representation provides a holistic perspective of an overall architecture of FEMS.

Function axis:

- Monitoring
- Analysis
- Optimization
- Instruction

Automation axis:

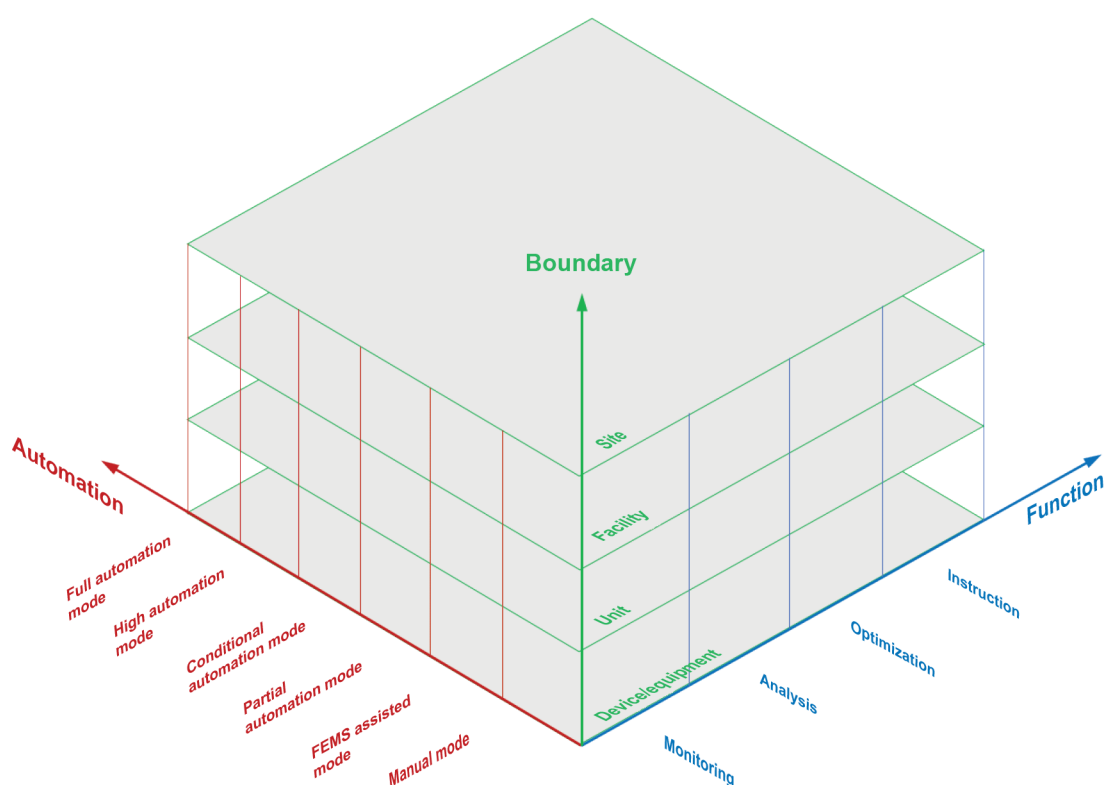
- Automation level 0: Manual mode (No Automation)
- Automation level 1: FEMS assisted mode
- Automation level 2: Partial automation mode
- Automation level 3: Conditional automation mode
- Automation level 4: High automation mode
- Automation level 5: Full automation mode

Boundary axis:

- Device/Equipment
- Unit
- Facility
- Site.

As an example, the classification of FEMS in use cases for information exchange among FEMS, production facilities, and energy supply facilities is described Annex A and illustrated in Figure A.2.

Table 7 depicts details of the FEMS functions on the two-dimensional plane of function axis and automation axis as examples. The FEMS can be classified into 6 automation levels from 0 to 5 by the level of automation.



IEC

Figure 18 – Three-dimensional map of FEMS

Table 7 – Relation between the level of automation and function

Automation level	Narrative definition	Monitoring	Analysis	Optimization	Instruction
Manual Energy Management System					
0	Manual mode	Energy-manager performs all aspects of the energy management task.	Collecting actual/reference data (e.g., monthly date for bill) manually.	KPIs are provided by management. KPIs are monitored manually. KPI values are calculated manually.	Manually provided based on knowledge and experience. Updated KPIs reported manually. Setting values for facilities are manually input.
1	FEMS assisted mode	System collects actual data and visualizes it to assist energy manager.	System collects some actual/reference data.	KPIs are manually defined. KPI values are calculated based on formula containing system suggested values.	Provided based on system suggested KPI values. Energy consumption and updated KPIs are reported and visualized by the system. Setting values for facilities are manually input.
2	Partial automation mode	System monitors and estimates unmeasured data/parameters. System visualizes KPIs and actual/reference data.	System collects actual/reference data.	KPIs are manually defined. KPI values are calculated by the system. Unmeasured parameters are assumed by the system. Change in energy performance is detected manually. Causality is estimated manually. Potential of energy saving is analysed manually.	Provided based on system suggested KPI values. Energy consumption and updated KPI are reported and visualized by the system. Setting values for facilities are manually input.

Automation level	Narrative definition	Monitoring	Analysis	Optimization	Instruction
Automated Energy Management System					
3	Conditional automation mode	System can perform all management tasks, including collaborative optimization with multiple systems in the steady-state operation or certain batch phases. Manager still needs to respond appropriately to the system's requests, etc.	System collects actual/reference data. KPIs are manually defined. KPI values are calculated by the system. Unmeasured parameters are assumed by the system. Change in energy performance is detected by the system. Causality is estimated manually. Potential of energy saving is analysed manually.	Some facilities are optimized based on the KPI values done manually.	Energy consumption and updated KPIs are reported and visualized by the system. Setting values for some facilities are input by the system.
4	High automation mode	- System performs all managing tasks within certain boundaries. - If constraints are not satisfied under the production plans, the equipment operation plan are adjusted by manual.	System collects actual/reference data. KPIs are defined by the system under normal operating condition. KPI values are calculated by the system under normal operating condition. Unmeasured parameters are assumed by the system. Change in energy performance is detected by the system. Causality is estimated by the system under normal operating condition. Potential of energy saving is analysed by the system under normal operating condition.	All facilities are optimized based on the KPI values done by the system under normal operating condition.	Energy consumption and updated KPIs are reported and visualized by the system. Setting values for all facilities are input by the system.

Automation level		Narrative definition	Monitoring	Analysis	Optimization	Instruction
5	Full automation mode	System performs all managing tasks.	System collects actual/reference data.	KPIs are defined by the system under all known conditions. KPI values are calculated by the system under all known conditions. Unmeasured parameters are assumed by the system under all known conditions. Change in energy performance is detected by the system under all known conditions. Causality is estimated by the system under all known conditions. Potential of energy saving is analysed by the system under all known conditions.	All facilities are optimized based on the KPI values done by the system under all known conditions.	Energy consumption and updated KPIs are reported and visualized by the system. Setting values for all facilities are input by the system.

7 FEMS Demand Response

7.1 Demand Response

Plants can adjust their energy demand with changing production plans and facility operation plan and utilize energy storage system such as batteries based on the status of energy balancing in the Smart Grid. Incentive-based demand response and price-based demand response are two kinds of programs applied by the Smart Grid to maintain grid energy balance through managing customer load demand in response to supply conditions, such as prices or availability signals. Some typical demand response programs for grid management are illustrated in Figure 19. The information exchanges between the industrial facilities and the smart grid in the demand response execution process are described in IEC TS 62872-1 and IEC 62872-2 [2]. FEMS is expected to play big roles in adjusting energy demand in industrial facilities and energy supply from them.

Using FEMS, industrial facilities can predict the energy demand under their future production plans and the facility operation plans for the production facilities. They can make facilities operation plans for energy supply facilities, including energy storage systems and power generation systems, corresponding to the predicted energy demands. Receiving requests to change energy supply or demand plans from the smart grid, the industrial facilities consider whether the request will be accepted or not by changing their production plans and facility operation plans.