Microgrid Energy Management Systems: Technologies and Architectures – AReview

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***Abstract*—The energy management concepts for Microgrid (MG)systemhadsubstantialattentioninthelastyears.Theaim of integrating an Energy Management System (EMS) in MG and/or building is to improve the energy efficiency and reduce the energy cost. This article gives an overview of different MG electrical architectures and some popular MG concepts with EMS. Some Artificial Intelligence based (AI) methods, in the EMS field, such as Artificial Neural Networks (ANN), Fuzzy Logic (FL), Machine Learning (ML) and Expert System (ES) are alsoexamined.**

Keywords—Microgrid, DC MG, AC MG, Hybrid MG, EMS, Artificial Intelligence, Machine learning, Fuzzy Logic, Expert system, Neural Networks.

I. INTRODUCTION

ThedescriptiongivenbythespecialistsinthefieldofMG [1,2,3] is ample. It defines the MG rightly, as anaggregation of sources and loads. The MG system concerns, allow many researchers to develop many technologies of Energy Management System (EMS) [4, 5]. They have a common goal: to continuously meet the needs of the facility, ensure maximum use of the energy produced, minimize the cost of this energy and reduce storage [4,6,7]. The impact of this technologynotonlyintermsofenergyefficiencyandcostbut also on the environmental aspect[8,9,10].

In the recent years, the Energy Management System (EMS) and Artificial Intelligence (AI) have become extremely important.

Inrecentyears,theArtificialIntelligence(AI)andEnergy Management System (EMS) have become extremely important. To mitigate climate change and increase energy efficiency,researchershavestudiedawiderangeofsolutions like Microgrid (MG), Smart Grid (SG), storage system, IntelligentEnergyManagementSystem(IEMS)andsoon.

In the concern of EMS, several methods and strategies havebeendeveloped.Theauthorin[5]summarizesdifferent energy management methods on Microgrids. An EMS is usually integrated within an MG to manage efficiently the intermittent renewable resources using a control system concept [11].

This paper aims to summarize some approaches used for energy management in Microgrid systems and their diverse architectures So, the MG system is briefly introduced in Section 2 and the MG electrical architecture is depicted in Section 3. The first part of Section 4 deals with some energy management approaches used both in standalone and connected MG. The second part represents, the different technologiesandsomeArtificialIntelligence(AI)methodsin theEMSdomain.Theconclusionanddiscussionaregivenin the lastsection.

II. MICROGRID SYSTEM

The authors in [12] defined an MG as a low-voltage distributionsystemconnectedtomodulargenerationsystems. In [13], the authors refer the MG as an integrated system in which Distributed Energy Resources (DERs) create a grid that provides energy to distributedloads.

An MG system is composed of one or more production sources,thesesourcesarebasedonRenewableEnergies(RE) such as Photovoltaic Panels (PV) and Wind Turbines (WT). Also, we can find a conventional sources like batteries for energystorage[14,15,16].However,themajorobstacletothe developmentoftheMGsystem,basedonRenewableEnergy (RE), is their intermittency due to the meteorological parameters, they depend on heavily [16]. The production sources are also coupled with an external power source, publicelectricitynetworksoradieselgenerator[17].Theuse of this conventional source is one of the solutions that can limit this intermittence[9,18,19,20].

Indeed, integrating these solutions helps to avoid the mentioned drawbacks of renewable energy [21,22] and permits the continuity of service when the meteorological parameters do not allow energy production or the storage system is not sufficient, but it requires a big investment to cover the demand [18, 20].

An MG has two operating modes: an autonomous mode (OFFGRID) or standalone MG and a connected mode to the network (ONGRID) [12,16,23,24]. In stand-alone mode, the MG can be unrelated from the main grid due a geographic isolation or to the failure of the main grid. When the power produced by the RE sources is less than the demand, the batterysuppliesthedeficit[9],inthecasewherebothREand battery are not sufficient, the diesel generator operates to supply the demand. The MG considered the grid-connected mode as an integral part of the power system, when the productionsourcesarelessthanthedemand,thenitswitched to the public grid network[25].

III. ELECTRICAL ARCHITECTURE OF AN MGSYSTEM

In[25],theauthorsdescribeaMGsystemasanelectrical energy architecture that aggregate sources, loads andstorage which can be controlled by anEMS.

Moreover, the MG electrical architecture can be the one from the three following types: Direct Current (DC) MG, AlternativeCurrent(AC)MGandHybridAC/DCMicrogrid [21,23,26].

A. *Alternative Current Microgrid (ACMG)*

The Fig. 1 depicts an Alternative Current (AC) MG Electrical architecture. The concept of AC MG requires that the AC sources supply AC loads like microwave oven, hairdryer, common lighting, Dishwasher, Refrigerator, Washingmachineandso.InthecaseofsupplyingDCloads, which exist in the majority of buildings, a bi-directional inverterisusedtofeedtheseloadsthataredifferentfromthe source.

The paper [24] gives a review of AC MG components, thataredifferentfromeachother,butoneormorerenewable sources are important in an AC MGsystem.

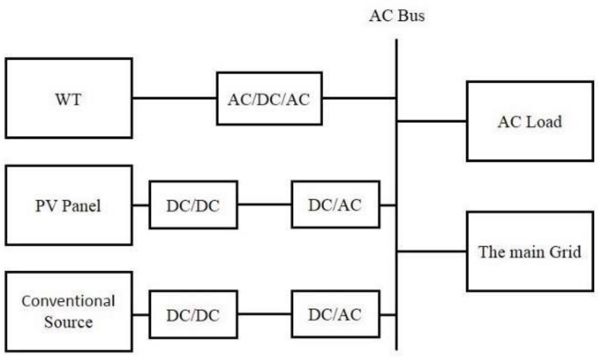

Fig. 1. Alternative Current (AC) MG Electrical architecture.

B. *Direct Current Microgrid (DC MG)*

The Fig. 2 illustrates a typical diagram of the DC architecture configuration of an MG. The DC MG is the conceptfacingthedemandoftheusersaswellasmostofthe loads are DC loads such as light-emitting diodes (LEDs), laptopbatteries;cellphonebatteries,Wirelessinternetrouter and so.

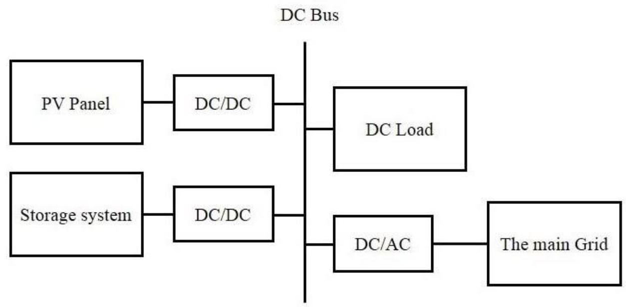

Fig. 2. Direct Current (DC) MG Electrical architecture

In [16] the authors propose a basic structure of the DC standalone MG. This structure consists of PV panels, WT, battery storage and fuel cell.

In the literature, there are several structures from which the author in [24] gives a general overview of different structures and components used in many kinds of research. The DC MG does not have a reactive power, it is much simplerunlikeACMG[24].Additionally,theauthorsin[18] refer to AC and DC loads and the value-added if DC loads are fed directly from the PV source that is already in DC mode.

In[27],theauthorsproposethattheDCelectricitysources shoulddirectlysupplyDCloads.Formorerenewableenergy efficiency, a bi-directional inverter is introduced to control and limit DC-grid voltage within a givenrange.

Table 1 gives a review in terms of the advantages and disadvantages of DC and AC electrical architecture. Inorder toreducetheinstallationcostsforanMG,itissuitabletofeed it with a high number of AC loads. For offices and data center, DC Microgrids are more appropriate, they include more DC loads[13].

TABLE I. ADVANTAGE AND DISADVANTAGE OF DC AND AC ELECTRICAL ARCHITECTURE.

Type	DC architecture	AC architecture
Advantage [26, 28, 29]	More efficient: It can transmit more power with the minimum losses over long distances. Lower cost: Higher efficiency means lower transmission cost Improved reliability: High-voltage direct current (HVDC) transmission can improve systemstability. Compatibility: Modern electrical loads and renewable energy sources are DC. Stability: The only electrical quantity that needs to be supported is the DC bus voltage.	Simplicity: at the level of generation, transmission and distribution. Availability: The majority of electrical equipment used in the market is compatible to AC. Simplicity: AC power can intensify very easily and efficiently. Safety: CAs has been shown to be safer for humans. Compatibility: It is compatible with the existing public network.
Disadvantage [26, 28]	DC circuits are not compatible with electrical safety tools. Existing building codes and standards are specific to alternating current. DC power has different insulation, safety requirements due to the nature of DC power.	The AC transmission line generates a lot of electrical losses. Unstable, problem of the reactive power.

C. Hybrid micro-grid AC /DC

TheHybridAC/DCMicrogridcombinesboththeACand theDCconcepts.Fig.3showsatypicalexampleofaHybrid architecture that contains green sources, battery, AC andDC loads.

However, it exists a multiple presentations of Hybrid conceptsintermofcomponentdefinitionandthelevelofthe adopted electrical architecture [12,30].

Theauthorsin[31]consideranisolatedhybridMGwhere everyDCsourcecoupledwithDCloadsandACsourceswith AC loads. The same concepts are defined in [32] whereas generatedpowerisswappedamongstbothACandDCedges utilizing a bidirectional mode converter. In the same referencetheauthorsgivealsoareviewofMGtechnologies.

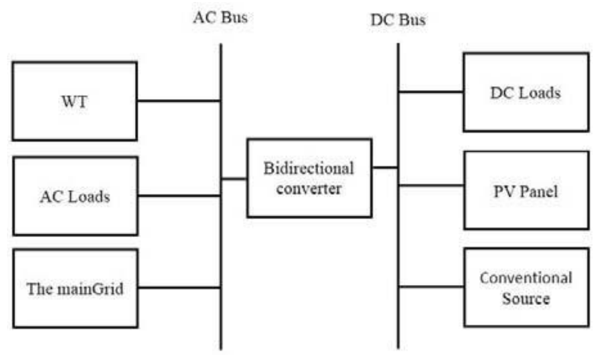

Fig. 3. Hybrid AC/DCMicrogrid

In the few next decades, the AC Network is expected to be dominant due to the existing infrastructure [26]. But the hybridconceptwillbemorepopularinthenextfewyearsfor the following reasons[26]:

- The loads evolution from the AC to DCconcept.
- The integration of RE sources and electricvehicles.

Also, the authors in [33] also summarize the advantages which help to choose the Hybrid concepts solution. From these advantages we can mention:

- The elimination of unnecessary multi conversion processes.
- The connection of all DC loads to the DC side will facilitate the control injections into the AC side through the main converters, thus guaranteeing high-quality AC in thegrid.

IV. ENERGY MANAGEMENT SYSTEM TECHNOLOGIES AND METHODS

The principal function of the EMS is to reduce energy consumption using smart devices, to improve energy efficiencyandcustomercomfort.Inabuilding,itisnecessary tocontrolandoptimizetheenergyuse.So,theintegrationof an EMS isneeded.

The authors in [34] consider that home energy management systems make residential customers aware of energy efficiency, comfort and support the energy system.

Indeed, the energy management systems based on historical data, statistical methods, forecasting techniques, and load estimation will be most used in the future, owingto thegrowinguncertaintiesinfutureresidentialenergyprofiles and appliance types.

According to [35], the real-time energy management ofa building can reduce the energy bills and then the primary energy consumption. The authors in [36] present an innovative approach to achieve energy management in the zero-energy building using smart loaddevices.

Theuseofintelligentenergymanagementisimportantin an MG system to ensure the optimal energy consumed and reduce the cost. This need is necessary both for the standalone/OFFGRID systems and connectedones.

A. Energy Management System (EMS)

ThissectionreviewsthevariousEMSapproachesusedin standaloneMGandgrid-connectedMG.Table2summarizes the research done in the field of EMS in different MG types. It describes the use of energy management in several domains.

In the literature, many parameters can contribute to the operation of an MG system such as the size of production source,storageanddieselgenerator.Certainly,agoodenergy managementprovidesanefficientenergysource,thusalow cost or an important Return on Investment (ROI), and decrease in CO2 emission results. Table 2 summarizes some different MG concepts using the EMS, like the stand-alone MG, the main connected Grid and Electricvehicles.

B. EMS Technologies andmethods

In many researches, some methods and technologies in the field of EMS are used. The authors in [6] investigated an applicationofamulti-agentsystemforcyber-enabledenergy management of buildingstructures.

In [41] authors propose a renewable generation forecast strategy. The grid compensates, at any times, the energy imbalance, whereas the battery is used to smooth daily fluctuations and drift between the measured and forecasted energy. In [5], authors presented several approaches on the techniques and methods used by researchers for EMS. Such as genetic algorithm (GA), Differential Evolution (DE), neural network, fuzzy logic, and Neuro-fuzzy, and so.

In[43],theOnlinelearningisalsousedtoadaptlongterm changes. Also, different tools have been used in ML, including ANN, Logistic Regression (LR), Deep Learning (DL) combined with time series, Support Vector Regression (SVR), Regression Tree (RT) andso.

Authors in [25] gave a short outline for the use of the FL toperformanEMSandpresentadesignofalowcomplexity FL Controller for a residential grid-connected MGEMS.

A review on the applications of ANN in the field of energy, especially for predicting the performance of solid desiccant cooling systems, is presented in [44].

[45] summarizes the machine learning techniques and models utilized for building energy forecasting and benchmarking to indicate the advantages and drawbacks of each model. Also, this section also discusses the advantages

and drawbacks of some technologies and methods of Artificial Intelligence (AI) in the EMS field. Such as ArtificialNeuralNetworks(ANN)[46,47],FuzzyLogic(FL) [47], Machine Learning (ML) [43] and Expert System (ES) [48,49]. Table 3 depicts some advantages and disadvantages of this technologies.

TABLE II. DIFFERENT MG CONCEPTS *USING* EMS.

Domain	Reference	Description of the use the energy management
Stand Alone MG	[37]	The author proposed a techno-economic analysis and they developed a hybrid system design that include PV panels, battery system and microturbine as a backup source in Palestine.
	[38]	It presents a hybrid autonomous energy system using hydrogen storage to meet the load need.
	[39]	A climate forecast predictive model control (MPC) was applied to an energy management analysis in an islanded domestic system.
	[40]	A battery management strategy was presented for charging and discharging batteries in a hybrid renewable energy system in order to manage the flow of energy between the different system components.
MG Connected to the maingrid	[41]	The author presents an energy management strategy for MG consisting of PV, WT and battery linked to the Grid.
	[8]	The author studies an energy management strategy adopted by HOMER was followed to execute the simulations.
	[25]	This paper reviews several EMS strategies based on FLC.
Electrical vehicles	[10]	This paper studied a collaborative decision model to optimize flow of electricity in commercial buildings, charging stations of Electric Vehicle (EV) and Grid under the uncertainty of energydemand
	[42]	A genetic algorithm can be applied to optimize the size of a hybrid photovoltaic/ battery system connected to the Grid in conjunction with a home EMS in different charging/discharging scenarios of a plug-in electric vehicle.

TABLE III. ADVANTAGES AND DISADVANTAGES OF EMS METHODS.

Domain	Reference	ADVANTAGE	DISADVANTAGE
Expert System	[48,49,50]	Program development flexibility. Superior problem solving. Reliability and Availability. Work with incomplete information. Fast response and Consistency. Combined knowledge.	High development costs. Only work well in narrow domains. Not all problems are suitable. Probable system complexity explosion due to problem size and consequences of actions.
Machine learning	[43,45]	Flexible with different tools. Self-learning/modifying and Intelligent decisions. Low cost and Easy installation. Privacy protection. Reliability and Availability.	Need a lot of labeled data. Works with continuous loss functions. Large data requirements.
Artificial Neural Networks	[44,45,46, 47]	Self-learning and Continuity of service. Flexibility and compatibility with other application. Speed and Simplicity of implementation Attractive attributes of identification and non-linear control. Appropriate for non-mathematical models. Capable to manage abundant number of data and input variables.	The functioning of the neural network needs training. Takes a long time to process the large neural network. Spending a lot of time for offline training. Quality predictions need a lot of data.
Fuzzy logic	[25,47,51]	Intuitive design model. Similar to human reasoning. No mathematical modeling is required. Rules and functions. Rapid operation. The control action is proved by the rules.	Stability is not assured. Obligatory attention for the control of critical systems The lower speed and slower run time. Lack of response in real time. Not able to receiving feedback for implementation of learning strategy. Limited number of input variables usage. Incapability to advance optimal fuzzy rules number and determine the membership function parameters.

V. CONLUSION

In this paper, MG overview architecture is presented and discussed, as well as a summarized investigation on the AC-DC bus architecture advantages and disadvantages.

Hence, the EMS utilization in MG is becoming increasingly widespread. Likewise, many research works provide some energy management systems such as ML, FL, ES and ANN in order to reduce the electricity cost and to support the trend towards a more sustainable and reliable green energy suppliers.

Further studies, in literature, prove that the ML approach is the most used to obtain efficient results, with a low cost, flexibility, reliability, availability and so. Moreover, the ML canbeextendedanOnlinelearningforlongtermchangesfor large-scaledeployments.

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