Survey of Multiagents Systems Application in Microgrids

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Abstract— **Microgrid will constitute the heart of the next generation of power systems. They are expected to incorporate more distributed generation (DG) mainly coming from renewable energy (RE). They are characterized by their ability to manage and control electricity by using the advance of information technology. In parallel, development of multi agent systems (MAS) and their tested proprieties increase researchers interest in applying them in Microgrid (MG) context.**
This paper presents a survey of MAS application in MG. It revisits the concept of MG and MAS. It introduces the agency domain and its characteristics. MAS design methodologies and implementation platform are also reported.

Keywords-component; Smart Grid; Microgrid; Multi-Agent System; MAS design; JADE;

I. Introduction

The concept of smart grid (SG) brings a new flux to power system: information flux as well as two way power flux. This flux is mainly happening at the advanced metering infrastructure (AMI) in order to measure power parameters at different grid levels. These measures will make it possible to the grid operator and costumers to manage their power consumption through demand-side management and apply energy efficiency strategies. In addition, Microgrids (MGs) are currently being developed as a potentially effective strategy to integrate distributed energy resource (DER) systems at customer's sites with the ability to feed power directly to low voltage (LV) networks, thereby allowing the customer to become an active participant in the SG. In developing countries, such as Morocco, there is an opportunity for a widespread development of MGs where SG will be composed of a mesh of MGs to provide efficient and reliable energy. In this perspective, MGs will represent the inner cell of SG. So, managing the SG will lead to managing different MGs in a harmonized manner.

Different standard bodies have been actively involved in developing standard for SG. In the United States, the National Institute of Standards and Technology (NIST) has the responsibility to coordinate development of protocols and standards for information management to achieve interoperability of Smart Grid devices and systems[1]; NIST developed a conceptual model that divides the SG into seven domain: costumers, market, service providers, operations, bulk generation, transmission and distribution. Each domain represents specific actor in the SG system. More recently, International Telecommunication Union (ITU) report [2] of the working group 3 studied these domains from an Information and Communication Technologies (ICT) perspective and simplified them to five: service provider, communication, smart metering, grid and customer domains. The report studied the functional model of each domain.

Fang, [3] presented different way of analyzing the SG by considering three main functional areas:

- Smart infrastructure system: It includes usual power system infrastructure: power generation, transmission and distribution; and the information infrastructure such as sensors, and the communication infrastructure that includes wired and wireless technologies.
- Smart management system objectives are energy loss minimization, and optimization techniques;
- Smart protection system discusses system reliability and failure protection mechanism in addition to security and privacy issues.[3]

Smart management system utilizes the information and communication technologies to provide real time data collection, visualization and control. In particular multi-agent systems (MAS) are being explored to implement smart agents for MGs. The purpose of this paper is to survey MAS application in MG and their design methodologies. The second section will introduce the MG and their role in future power systems. The third section will investigate the agent concept and the motivation of using such system in MG. The standardization foundation of MAS will also be presented. The fourth section surveys the literature for demonstrative examples of MAS application in MG. Two main applications are reviewed: power systems operation and control through MAS and integration of MAS with power simulator in order to implement a test bed for MG simulation. The last section describes methodologies of implementing MAS and presents some platform that could be used for this aim.

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II. Microgrids the core of the next power systems generation

Last decades have known a great integration of distributed generation in the power system. Electricity coming from wind energy resources has reached 370 GW of installed capacity in 2014. Solar energy presents an installed capacity of 177 GW in 2014.[4] Conventional power systems were not designed to handle these distributed generations. Power flow normally goes from the power plants to the consumers; however, with the distributed generations the consumers can also produce electricity which raises a number of technical problems such as power quality and voltage stability. Over the coming years, the high future penetration of micro sources will change the passive distribution network behavior. Instead, it will participate to the power balance of new injected renewable energy. The systematic solution to handle this new and complex configuration of the power network is to divide it into small subsystems. Each subsystem will be considered as a small power grid. In addition to classical tasks of keeping the balance between the supply and demand, and regulating electrical parameters in a power grid, these clusters will also have intensive use of communication technology. These clusters have been called: Microgrids.

The literature review shows different definition of MGs, but it can be deduced that a MG has some main characteristics:

- A MG integrates micro-generation and consumer's loads in the local distribution level. Storage units could also be added.
- A MG has to be able to handle both grid-connected mode during normal operation and islanded mode during emergency operation.
- Besides the former elements, a MG has an active behavior in controlling and managing local micro-sources and controllable loads such as load shedding strategy in islanded mode operation.

There are minimal components that a low voltage system must have in order to be considered as a MG. The mandatory components are: micro-sources, load, the connection with the main grid and the system controller. Additional components can also be added such as controllable loads, electrical vehicles and storage units.[5]

In the literature review, a MG could also be considered as the system that incorporates several houses with DG and is connected to the main grid through a low voltage feeder. In other configuration, it can be a bigger system that comprises small wind and PV farms in addition to the houses.

The following sections will focus on control and management function in a MG. A special attention will be given to Multi-agent based systems.

III. MAS Concepts

This section will introduce the concept of an agent, its characteristics, the difference between using an existing systems and an agent based approaches and the additional benefits generated by using such system.

A. Agent Concept

A multitude of definitions were proposed in computer science literature in order to define what an agent is. However, all of them agree on some essential characteristics without them, it is not possible to call an entity an agent.

An agent is defined as an autonomous entity (software or hardware) that reacts according to its environment, takes decisions autonomously in order to achieve its goals and communicates with its peers. Three aspects are highlighted: the environment, the autonomy and the communication. The agent is distinct from its environment that constitutes the outside world; he can interact with this environment by sensing some data to get a partial idea of what is happening. He also takes actions that modify the environment in a way to reach its own goal. The autonomy aspect is one of the key elements of MAS. When the environment changes, an agent has the ability to react and take actions autonomously. Some researchers consider that an agent can also take the initiative of executing the appropriate operation as part of its intelligent autonomy. The third important aspect is the communication. An agent must be able to communicate with its peers; that represents his social ability. The agent must be conceived in a way that exceeds the function of passing a data to another program; but it allows to the agents the ability to cooperate between each other and reach the optimal configuration.[6]

As a consequence, the MAS could be considered as an aggregation of different agents. MAS may or not contain agents that communicate between each other, even if the communication aspect is one of the most important factors that differentiate MAS from other technologies.

B. Added value of applying MAS in Microgrids

MAS have known a great development last years. Their interesting characteristics make researchers investigate their applications in power systems. A summary of different research in the literature review that investigated the MAS from 1998 onwards are also provided in [6]. Four active research areas on MAS are found: protection, monitoring and diagnostics, modeling and simulation, and distributed control. Most of researches are done on the two last areas.

The MAS presents a set of characteristics that make it more competitive for MG. The distributed nature of MAS makes it suitable for MG environment. Besides, their characteristics of being flexible, extensible and fault tolerant are usually used as justification for their adoption. Flexibility means that the agent can choose from a set of actions the most appropriate one. This could be illustrated by the ability to build a new plan if a particular control action fails. [6] Extensible means that the system can add new functionalities without altering the existing one. This point alone has a great added value. For example, in a MG environment, new components such as new sensors could be added. It is very important that the already operating system would integrate the new sensors functionalities without re-implementing the whole system. When there is a need to extend the control of the MG, one easy solution could be to extend the MAS as well. A new agent is deployed for the new task and easily integrated with existing system. The system also become more fault tolerant when using MAS. In current systems, redundancy is one of solutions to make the system more faults tolerant. In MAS redundancy means duplicating an agent. Furthermore, the second agent could be designed for emergency situation and could be more optimal than the one used in permanent regime. This is possible as the emergency agent could have different priorities and structure than the one operating in permanent regime.

The reference [7] gives more details on the advantages of MAS compared to a simple optimizer, a digital closed-loop controllers and learning systems.

Secondary control also referred to as the MG energy management system (EMS) is responsible for the economical and reliable operation of the MG and this functionality. [8] This literature review categorizes two main EMS: centralized and decentralized ones. Decentralized EMS have been primarily addressed in the literature by using the MAS framework according to [8].

C. *Standardization foundation for MAS*

Recently, the Foundation for Intelligent Physical Agents' (FIPA) standards has become the reference for MAS standards used by computer science developers' community. The main objective is to make sure that MAS designed by different organism would communicate between each other; and also develop architecture guide lines for implementing MAS.[9]

The FIPA Agent Management Reference model gives an open architecture for MAS. According to FIPA, the agent platform is the environment where an agent can live and perform its tasks. Each platform has two default agents: Agent Management System (AMS) and Directory Facilitator (DF). The AMS contains the identifier and states of all agents that exist in the platform. The DF is the agent that provides the default yellow page service in the platform. The Message Transport System is the part of the software that control message exchanges between different agents.

A message in FIPA Agent Communication Language (ACL) is characterized by 13 fields; The reference [10] define types of these messages.

IV. Application of MAS in Microgrids

Two main research orientations are found in literature review: the use of MAS as standalone application for power systems operation and control in MGs; and integration of MAS with power simulator in order to implement a test bed for MG simulation. [10]

A. *Microgrid operation*

Some researchers believe that MAS as a standalone solution would become the next control and supervision generation in MGs [11]-[14].

Architecture of MAS for substation is developed in [11]. The paper analyzes the nature of agents in the system and their different tasks. It also studies how communication between agents in the system is performed. Based on FIPA specifications, the MAS control system defines four types of agents: user, database, devices, information retrieval and remote control. It also defines two main types of modules: Global modules (or WAN), containing mostly user interface and database functionality, situated at the control center and offices. Local (LAN) modules contain functionality relevant to a particular substation, along with facilities for displaying local information and transferring it over the WAN.

The main agents in the system are the query broker and the request broker. The query broker helps the user agent to answer the user query by communicating with other agents. The request broker takes in charge online intervention. Another important agent used called mobile agent. This agent intervenes when a user look for some information in the system. The mobile agent contacts others agents retrieves data and send it back to the user agent. The advantages of such agents are greatest for low powered client devices and during intermittent connection [11].

A fully decentralized MG control approach based on MAS for market operation is presented in [12]. The model is based on auction algorithm (symmetrical assignment problem). The idea of the paper is to present an autonomous system that regulates itself and each agent determines its own set point based on different prices. It is interesting because it uses advantages of MAS and presents a fully decentralized control system. In this approach, the main responsibility is given to the DER controllers. DER controllers compete to maximize their production in order to satisfy the demand and provide the maximum possible export to the grid taking into account current market prices. This configuration demonstrated a limitation in number of bidders which should not exceed 30 objects. Otherwise, the algorithm will iterate more than 100 times which could take hours for running.

A more recent paper implements MG market operation using a Multi-agent based game theory reverse auction model. [13] Similar to the previous paper [12], this one presents a decentralized approach for market operation using reverse auction model in which prices go down in contrast to typical auction models. The aggregator agent sends to DER bidding agents utility base price and power demand for next hour. Its ultimate goal is to serve the required power demand with the lowest cost. DER bidding agents compare their own base price to the utility and submit if their price is lower than the other. The aggregator collects the bids and checks whether the demand is served or not. If the first qualified bidder covers all demand, the aggregator sends him the power reference; otherwise, it sends the power reference to other qualified bidders too. The system was implemented and tested in a university SG test bed.

Another interesting MG management scheme was proposed in [14]. It presents an EMS based on fuzzy logic. Three fuzzy logic blocks were implemented in the battery, micro-turbine and grid agents. Each one decides how much power will be generated based on information received from the strategy and balance agents. The proposed solution compared to a centralized method shows that the operating cost was reduced when the market price is high.

A hierarchic decentralized control using MAS in actual MGs is investigated in [15]; Hybrid multi-agent control model is proposed to implement the hierarchical control framework with four levels. The first control level solves the local reflex controls such as breakers and protections. The second one implements the local optimization. The third level represents the decentralized control where agents of the system communicate between each other in order to find the optimal common solution. The fourth level is the centralized control. It takes into consideration the previous optimal solutions found, and runs the global optimization of the whole system. The control model is tested through different scenarios. Communication time delay is calculated at each level. The model proves its efficiency. However, the tested scenario is simpler than real MG context. The paper proposes at the end to use more complex tests for future works.

A Multi-agent-based dispatching scheme for distributed generators for voltage support on distribution feeders is presented in [16]. This paper presents MAS as auxiliary service that supports voltage regulation on distribution feeders. Agents are implemented on the local controllers on the voltage regulator and DGs that can act as supervisory controllers to the local controller.

B. Test bed platform simulator

It is important to conduct power simulations before deploying real power system configuration.

An integration of MAS with Supervisory Control and Data Acquisition (SCADA) systems is presented in [17]. The objective is to provide a framework to test innovative power systems applications using MAS.

SCADA as defined in [18] encompasses the collecting of the information via a remote terminal unit (RTU), transferring it back to the central site, carrying out any necessary analysis and control and then displaying that information on a number of operator screens or displays. Testing the integration of MAS an SCADA is compulsory for an easy deployment.

The paper presents an integration of SCADA and MAS with a simulation module. This module is built on Matlab/Simulink and simulates the system before its real implementation; it is integrated with SCADA using User Datagram Protocol (UDP) sockets. The author also indicates that the work is based on open source technology: Argos as SCADA system and Java Agent DEvelopment framework (JADE) as agents' platform, so other researchers can use the system later and adapt it to their needs.

One agent is designed to establish the communication and acquire data stored by SCADA systems. This agent communicates with the recorder and understands its language based on XML. When he gets the data, he forwards it to other agents through Agent Communication Language (ACL). Communication with sensors is carried by the SCADA system as usual. The results obtained have demonstrated the viability of the scheme proposed. However, the authors pointed out that a synchronization time between the SCADA and simulation module must be established.

A real industrial application of MAS automation is addressed in [19]. It presents an integration design of the current SCADA system with a MAS and Enterprise Service Bus (ESB). The main added value of this paper consists on using the ESB, MAS and simulation module. The simulation module is integrated with the global system, so it can use real data and simulate future potential actions. The simulation module and SCADA module are linked with the other part of the system through an ESB called Automation Service Bus (ASB). It provides features dedicated to industrial automation domain. ASB is used for semantic integration in heterogeneous engineering environments and provides data structures links to support the exchange of information between different engineering tools.

The agent platform is deployed in the industrial site on dedicated PC. Specific agents take in charge the communication with the Programmable Logic Controllers (PLC). It is an interesting architecture as it upgrades existing control systems. Such system can be used as transition to a fully decentralized one. According to the paper, future work will focus on self-organization aspects of the agent-based and contemporary industrial systems, such as SCADA and performance evaluation of architectures, and estimation of their scalability.

The paper [20] presents the two-layer power simulation framework that integrates the flexibility of agents into the power simulators to create a real-world SG test bed. The first layer of the framework consists of a control layer that contains the agent-based control. It provides decision-making, coordination and data management functionalities. The second layer functional or physical emulates the real power system through a power simulator. One important feature of this framework is that the functionalities of the physical layer like model parameters and data access of the simulation entities could be reached to the higher layer (control layer) through Service Oriented Architecture (SOA) mechanism. These services could be used by the control layer to request the physical layer to change parameters and to retrieve the simulation results. The advantage of that two layer configuration is that it is independent from platforms of each layer.

The paper [21] introduces a market operation of MG using MAS. The innovation of this work is the coordination of agent-based market operation with DER implementations which are undependably studied in the literature. DERs were implemented in Simulink and the MAS control scheme was implemented in Java agent development framework (JADE). The communication between the two environments was assured by multi-agent control simulation Jade extension (MACSimJX). This configuration minimizes the cost of the implementation of the real test bed and provides a complete test bed for MAS and DER operation.

V. MAS DESIGN METHODOLOGIES AND IMPLEMENTATION PLATFORM

This section will present the main MAS design methodologies and some tested platforms for agent implementation paradigm.

A. MAS design methodologies

Software engineering discipline studies theories, methods and tools for professional software process models development [22]. The main objective of these process models is to define a scheme and a template around which to organize and detail the studied process.

Agent-based computing introduces novel abstractions and programming structure. Classical methodologies are no more suited for such system. Thus, from software engineering point of view, novel and specific agent-oriented approaches are needed.[23] Different methodologies could be found in the literature for modeling MAS for instance ADELFE, Gaia, PASSI and ASPECS.[24] Each one of them models the system according to certain property. The following will focus on two methodologies: PASSI and ASPECS. The first is presented as an example of generic method for MAS modeling. The second presents a promising future MAS modeling based on holon aspect.

1) PASSI

PASSI (a Process for Agent Societies Specification and Implementation) is a step-by-step requirement-to-code methodology for designing and developing multi-agent societies integrating design models and concepts from both OO software engineering and artificial intelligence approaches using UML notation. [25] The models and phases of PASSI are:

System Requirements Model: An anthropomorphic model of the system requirements in terms of agency and purpose.

- Agent Society Model: A model of the social interactions and dependencies among the agents involved in the solution. Developing this model involves identifying roles that play this agent. Depending on the role, he will have different responsibilities. An extensive roles description that shows distinct tasks involved, communication capabilities and inter-agent dependencies is compulsory.
- Agent Implementation Model: A model of the solution architecture in terms of classes and methods.
- Code Model: A model of the solution at the code level.
- A Deployment Model: A model of the distribution of the parts of the system across hardware processing units. It involves use of deployment diagrams to describe the allocation of agents to the available processing units and any constraints on migration and mobility.[26]

2) ASPECS

ASPECS is a software engineering process that describes steps for software development, starting with the requirements analysis to code implementation and deployment on a specific platform. It is a MAS methodology for the analysis and design of complex systems. ASPECS proposes to associate MAS to holonic system. These systems have the characteristic of being complex. Such systems are modeled as hierarchy of agents (agents composed by other agents). The main steps of the methodology are:

- Requirements analysis aims to get an organizational description of the system. The objective of this step is to collect available knowledge on the problem domain and organize it in an ontology diagram.
- The design of an agent community which is build on MAS model and have a global behavior that presents a solution of the problem described in the precedent phase.
- The implementation of the solution describes the architecture of the agents and shows the source code of the application.
- The application deployment is the final step where the application is deployed for use. [27]

The reference [28] presents more details on ASPECS methodology.

Basically both described methods above could be used in the MG context. However, PASSI would be more suitable for developers who want to test a MG management system that does not take into consideration the external system to this MG (for instance the management system of the MG of the other neighborhood). In contrast, if the developer would like to implement a more comprehensive system with several similar MGs, ASPECS would be more adequate.

B. Implementation platforms

Several agent-based simulation platforms were proposed. The following will discuss two main examples: JADE and JANUS.

1) JADE

JADE (Java Agent DEvelopment framework) is an open source software platform that provides basic middleware-layer functionalities which are independent of the specific application and which simplify the realization of distributed applications that exploit the software agent abstraction.[29]

The main advantage of JADE platform is that complies with the FIPA specifications. JADE is fully implemented in Java programming language. Additionally, it comes with graphical user interface tools. Plug-in tools for interfacing JADE with Matlab Simulink are also available.[30]

Further details on comparison between JADE, ZEUS and VOLTTRON platforms are discussed in [31]. Authors pointed out that JADE is best suited for experienced developers designing robust and scalable MAS control for MGs. ZEUS would be more suitable for novice developers that want to prototype and test MAS concepts. However, VOLTTRON adoption for MAS control of MGs in research and industrial applications is currently limited, compared to wide- spread use of JADE or ZEUS.[31]

2) Janus

Janus is an open-source multi-agent platform fully implemented in Java. It enables developers to quickly build multi-agent-based applications. The aim of mentioning this platform in this work is to present a new platform that is complaint with the ASPECS methodology already introduced in the previous section. The platform natively manages the concept of recursive agents and holons, and is a promising future research area.[32]

VI. Conclusion

Smart Grid is moving toward being a mesh of interconnected MGs that collaborate to provide efficient and reliable energy. From an information point of view, an interconnected system needs a way to communicate and share information for properly management and control. MAS could be a promising solution for MG control and management. This paper presents a review of MAS and their properties. The distributed nature of MAS and their ability to communicate and act autonomously make their application in MG a promising opportunity. Several examples of implementation of these systems have been developed and are presented in this paper. Design methodologies and MAS platform are reported in the paper. Development of new methods based on holon concept need to be investigate and improved for a wider use. However, more research must be conducted on how to exploit the communication advantage of MAS to improve efficiency and meet different delay requirements imposed by smart grid.

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